Arab Republic of Egypt
Ministry of Education
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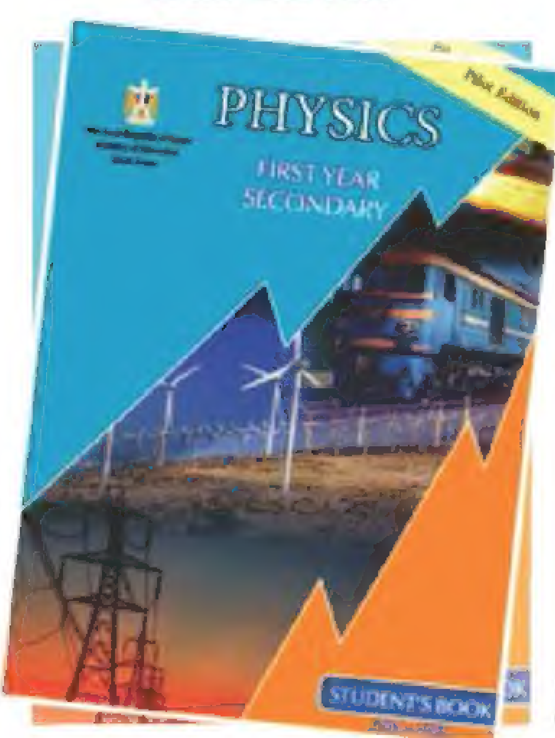
PHYSICS

FIRST YEAR SECONDARY

THIS COVER



This cover illustrates some forms of energy
and its different implementations

STUDENT'S BOOK

2019 - 2020

2019 - 2020

مقدمة

يمثل هذا الكتاب دعامة من دعائم المنهج المطور في الفيزياء للصف الأول الثانوي، إلى جانب الأنشطة والتدريبات، ودليل المعلم - الأمر الذي يعمل على تحقيق أهداف عملية تطوير المناهج لمواجهة تحديات القرن الحادي والعشرين، والذي واكبت بدايته ثورة متسارعة في المعلومات وتكنولوجيا الاتصالات.

ويهدف المنهج إلى تحقيق التوجهات التالية:

- التعبير بالعلاقة بين العلم والتكنولوجيا في مجال الفيزياء وانعكاساتها على التنمية.
- التركيز على ممارسة الطلاب للتصرف الواعي والفعال حيال استخدام المخرجات التكنولوجية.
- اكتساب الطلاب منهجية التفكير العلمي، ومن ثم يتاح لهم الانتقال إلى التعلم الذاتي الممتزج بالمتعة والتشويق.
- اعتياد الطلاب على الاستكشاف في التوصيل إلى المعلومات، واكتساب المزيد من الخبرات.
- توفير الفرص لممارسة مهام المواطنة من خلال أساليب التعلم الذاتي، والعمل بروح الفريق للتفاوض والإقناع وتقبل آراء الآخرين وعدم التعصب ونبذ التطرف.
- اكتساب الطلاب المهارات الحياتية، عن طريق زيادة الاهتمام بالجانب العملي والتطبيقي.
- تنمية الاتجاهات البيئية الإيجابية نحو استخدام الموارد البيئية، والحفاظ على التوازن البيئي محلياً وعالمياً.

ويحتوي هذا الكتاب على ست أبواب مترابطة، يتضمن كل باب منها مجموعة من الفصول المتكاملة تحقق الأهداف المرجوة من دراسة كل باب، وهي:

1. الكميات الفيزيائية ووحدات القياس.
2. الحركة الخطية.
3. الحركة الدائرية.

ومواكبة لتطورات العصر ولتفعيل تكنولوجيا المعلومات والاتصالات فقد تم تصميم موقع تعليمي على شبكة المعلومات الدولية والذي يتضمن العديد من الأفلام والصور والتدريبات والامتحانات وذلك على الرابط التالي:

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وقد تم تزويد الكتاب بروابط على بنك المعرفة المصري

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منها ما هو في سياق الموضوعات، ومنها ما هو إثرائي لتعميق المعرفة والفهم تشجيعًا للطلاب على المزيد من البحث والاطلاع.

نسأل الله عزّ وجلّ أن تعم الفائدة من هذا الكتاب، وندعوه سبحانه أن يكون ذلك لبنة من اللبنات التي نضعها في محراب حب الوطن والانتماء إليه. والله من وراء القصد وهو يهدي إلى سواء السبيل.

المؤلفون

Brief Contents

UNIT ONE: Physical Quantities and Measuring Units

UNIT TWO: LINEAR MOTION

UNIT THREE: Circular Motion

UNIT FOUR: Work and Energy in Our Daily Life

UNIT ONE

Physical Quantities and Measuring Units

Unit Chapters

Chapter One: Physical Measurements

Chapter Two: Scalar and Vector Quantities

Unit Introduction

Physical sciences are concerned with the study of all phenomena in the universe. They describe these phenomena trying to explore and examine them, aiming to benefit mankind. Describing these phenomena could not be reliable unless performing accurate measurement processes for the various physical quantities.

UNIT OBJECTIVES

By the end of this unit, you would be able to:

- Identify the fundamental and derived physical quantities.
- Derive the dimensional formula of physical quantities.
- State the fundamental physical quantities in the international system and their units.
- Name the tools used to measure length, mass, and time.
- Derive the international units of some derived physical quantities.
- Apply the dimensional formula to verify the physical relations.
- Compare the scalar quantities and the vector quantities.
- Perform the dot product for vector quantities.
- Perform the cross product for vector quantities.
- Identify how to find the error in measurement.
- Identify the reasons to have an error in measurement.

Scientific Processes and implied thinking skills:

- Scientific interpretation.
- Derive a conclusion
- Comparison
- Classification
- Problem solving
- Applying knowledge
- Critical thinking

Included affection objectives

- Appreciate the efforts of scientists in designing the measuring tools.
- Admire the advantage of performing accurate measurements.
- Realize the importance of measurement in daily life.

Chapter One

Physical Measurement

Expected Learning Outcome

By the end of this chapter you will be able to:

- Differentiate between the fundamental and derived physical quantities.
- Derive the dimensional formula of physical quantities.
- State the fundamental physical quantities in the international system and their units.
- Name the tools used to measure length, mass, and time.
- Derive the international units of some derived physical quantities.
- Apply the dimensional formula to verify the physical relations.
- Identify how to find the error in measurement.
- Identify the reasons to have an error in measurement.

Physical Terminology :

- *Physical quantity*
- *Measuring unit*
- *Absolute error*
- *Relative error*

Learning Resources

- Educational video: Physical Quantities and Measuring Units.
http://www.youtube.com/watch?v=[illegible]

Describing the temperature of a person as being high is scientifically inaccurate. Better to say that his temperature 40°C.

Figure (1): Man needs to carry out several measurements in daily life

What is meant by measurement?

Measurement is the process of comparing an unknown quantity with another quantity of its kind (called the unit of measurement) to find out how many times the first includes the second.The measurement process has three key elements:

1. The physical quantity to be measured.
2. The necessary measuring tools.
3. Units of measurement used (standard units).

We will discuss in details each element of these elements.

Go Further

For more knowledge about this topic you can refer to the Egyptian Knowledge Bank (EKB) through the opposite link.

1- Physical Quantities

The physical quantities that we deal with such as mass, time, length, and volume ... etc are called physical quantities. And we need to measure them accurately in our daily life.

Physical quantities can be classified into:

a) **Fundamental Physical Quantity:** is the physical quantity that cannot be defined in terms of other physical quantities.

Examples are: Length, Time, and Mass.

b) **Derived Physical Quantity:** is the physical quantity that can be defined in terms of the fundamental physical quantities.

Figure(2): A cuboid

Examples are: Volume, Speed, Acceleration.

For example,

Volume of a cuboid = Length × Width × Height

$$V = L_1 \times L_2 \times L_3$$

This means that volume is derived from length.

Moreover, there are several systems used allover the world to determine the fundamental physical quantities and their measuring units.

	Units of Measurement		
The Fundamental Quantity	**The French System (Gaussian System) (C.G.S)**	**The British System (F.P.S)**	**The Metric System (M.K.S)**
Length	Centimeter	Foot	Meter
Mass	Gram	Pound	Kilogram
Time	Second	Second	Second

Integration with mathematics

The physical quantities and their interrelationships can be expressed using mathematical equations. These mathematical equations give a shorthand illustration for physical relationships. Each physical equation has a particular indication. This indication is called the physical meaning.

International System of Units (SI) :

It is also known as the modern metric system. It is worthy to mention that in the General Conference of Weights and Measures that held in 1960. Scientists agreed to add other four fundamental physical quantities.

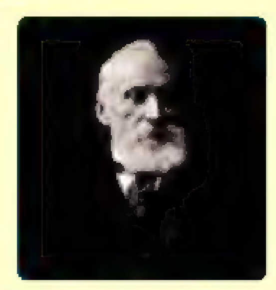
	The Physical Quantity		The International Unit	
1	Length	(L)	Meter	(m)
2	Mass	(M)	Kilogram	(kg)
3	Time	(T)	Second	(s)
4	Electric Current Intensity	(I)	Ampere	(A)
5	The Absolute Temperature	(T)	Kelvin	(K)
6	Amount of Material	(n)	Mole	(mol)
7	Luminous Intensity	(I_v)	Candela	(cd)

Two other units are added which are:

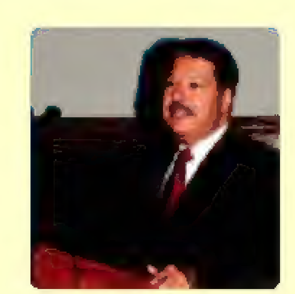
- Radian for the angle measure.
- Steradian for the solid angle measure.

Nowadays, the international system of units is used in all the scientific fields all over the world.

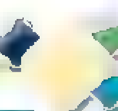
Distinguished Scientists



William Thomson: a British scientist, who played a great role in the development of the Metric System. He determined accurately the value of the absolute zero (the zero point on Kelvin scale). It was found to be – 273 °C



Ahmed Zeweil: an Egyptian scientist, who won Nobel Prize in 1999. He used laser to study the mechanism of chemical reactions among molecules in intervals measured in Femtoseconds (fs = 10^{-15}s)



2- Measurement Tools

Man in ancient eras used parts of his body and natural phenomena as tools of measurement. He used the arm, the hand span, and the foot as tools to measure length. Also, he benefited from the sunrise, the sunset, and the moon phases in devising a measure of time. However, various measurement systems originated and developed in different countries. The measuring tools have been tremendously developed in the context of the great industrial evolution next to the Second World War. Consequently, these tools were very helpful to man in describing phenomena accurately and exploring facts

3- Standard Units

Without using measuring units, most operations we perform in everyday experience become meaningless. For instance, when we say that the mass of an object is equal to (5) without giving a unit of measurement, that makes us puzzled. Is it in grams, kilograms, or tons?

On the other hand, saying that the mass of an object is equal to (5 kg), the quantity would be fully clarified.

Scientists have tried to figure out the most accurate definition for each of the standard units for length, mass, and time. And here are some of these definitions.

First: The Standard Length (The Meter)

French people were the first who used the meter as a standard unit for measuring the length. This definition has been changed aiming the most accurate definition.

The Standard Meter is the distance between two engraved marks at the ends of a rod made of platinum and iridium alloy kept at 0°C, at the International Bureau of Weights and Measures near Paris.

Figure (3) the Standard Meter

Enrichment knowledge

In 1960, scientists agreed in the General Conference of Weights and Measures to replace the previous definition of the standard meter with the following one which is related to atomic radiation.

The Standard Meter is equal to a specific number of wavelengths (1650763.73) of the red – orange light emitted in vacuum by the atoms of krypton (atomic mass 86) contained in a discharge tube.

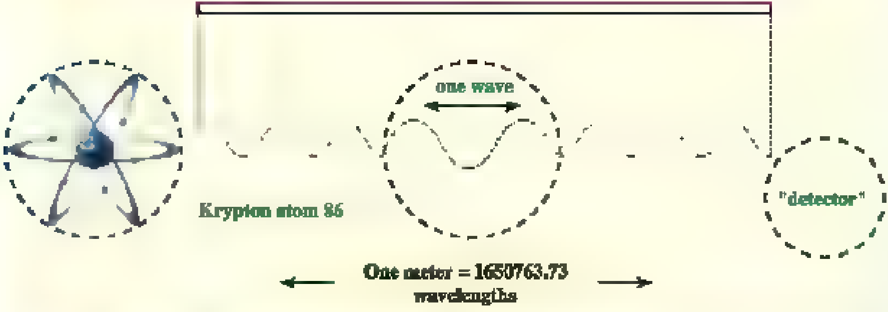


Figure (4) : The meter in terms of the wavelength of the red-orange light emitted by the krypton atom 86

Inspiring creativity

Using the internet, find out an answer for the following questions:

- How could you determine how far the moon is from Earth?
- How could you determine the circumference of Earth?

Second: The Standard Mass (The Kilogram)

The standard kilogram is the mass of a cylinder made of platinium and iridium alloy of specific dimensions kept at 0°C, at the International Bureau of Weights and Measures near Paris.

Figure (5): The Standard kilogram

Third: The Standard Time (The Second)

The second is the unit of measuring time. In ancient times, the daytime and the night time were proper ways to figure out an easy and acceptable measure for the time unit. That is because the day = 24 hours = 24 x 60 minutes = 24 x 60 x 60 =86400 seconds.

Accordingly, the second was defined as $\frac{1}{86400}$ of the average solar day.

Recently, scientists suggested using the atomic clocks such as the cesium clock to measure time due to their high accuracy.

Enrichment knowledge

Nowadays, the second is defined as the interval of time spent by the cesium atom (atomic mass 133) to emit a certain number of waves, specifically 9192631700 waves.

Figure (6): the cesium atomic clock

Using the highly accurate atomic clocks is very helpful in studying a lot of scientific and empirical issues such as the determination of the period of the Earth spin (the day length). Besides, checking up for aviation and navigations and verifying the journey schedule of space ships that explore the universe.

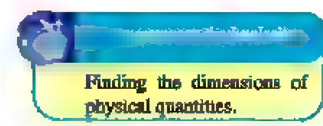
Critical Thinking Skills

- Why do not we use a glass model for the standard meter as a standard unit to measure length?
- Discuss in your point of view why scientists prefer the atomic standard meter rather than the international standard meter.
- Why do scientists always look for the most accurate standards to measure physical quantities?

Dimensional Formula

Scientists agreed to give a specific definition for each physical quantity. This definition is applied everywhere in the world. For example, the term speed expresses the rate of change of distance that equals $\frac{\text{Distance}}{\text{Time}}$. The symbol we use in this book to specify the dimension of .

- Length is "L".
- Mass is "M".
- Time is "T".



Finding the dimensions of physical quantities.

When we express the above mentioned definition in terms of the previous symbols, we get what is known as the "dimensional formula" of the physical quantity.

$$[v] = \frac{Distance}{time} = \frac{L}{T} = LT^{-1}$$

Accordingly, most of the derived physical quantities can be expressed in terms of the fundamental physical quantities which are Length, Mass and Time. Each of them has a particular exponent. Thus, we obtain the following general formula:

$$[A] = L^{\pm a} M^{\pm b} T^{\pm c}$$

Where A is the physical quantity and a, b, and c are the dimensions of L , M , and T respectively.

The unit of measuring the physical quantity:

We get the unit of measurement by substituting the symbols of dimensions by the proper units. For instance, the unit of measuring speed is m/s .

Solved Example

Find the dimensions and the unit of measuring acceleration, knowing that acceleration is the rate of change of velocity.

Solution:

$$\text{Acceleration} = \frac{\text{Change of velocity}}{\text{Time}} \qquad a = \frac{Velocity}{time} = \frac{LT^{-1}}{T} = LT^{-2}$$

The unit of measuring acceleration = m/s^2

The dimensional formula of some physical quantities:

The physical quantity	Its relationship to other quantities	The dimensional formula	Unit of measurement
Area	A = Length × width	$L \times L = L^2$	m^2
Volume	V= Length × width × height	$L \times L \times L = L^3$	m^3
Density	$\rho = \frac{\text{Mass}}{\text{Volume}}$	$\frac{M}{L^3} = ML^{-3}$	kg/m^3
Velocity	$v = \frac{\text{Displacement}}{\text{Time}}$	$\frac{L}{T} = LT^{-1}$	m/s
Acceleration	$a = \frac{\text{Change of velocity}}{\text{Time}}$	$\frac{LT^{-1}}{T}$ LT^{-2}	m/s^2
Force	F = mass × acceleration	$M \times LT^{-2} = MLT^{-2}$	*Newton (N)*

Pay Attention

- To add or subtract two physical quantities, they must be of the same kind having the same dimensions. You cannot add a mass of 2 kg to a length of 2 m.
- If the two quantities are of the same kind but having different units, one unit should be converted into the other unit to be added or subtracted.

$$1\ m + 170\ cm = 100\ cm + 170\ cm = 270\ cm$$

- Multiplying or dividing physical quantities of different dimensions gives a new physical quantity; for example dividing distance over time gives speed.

The importance of the dimensional formula: A useful procedure for checking a specific physical relationship is to use the dimensional analysis because dimensions can be treated as algebraic quantities. Accordingly, dimensions of both sides of the equation should match.

Solved Example

Show that the following relation is dimensionally correct. kinetic energy $= \frac{1}{2} \times$ mass $\times$ square of velocity given that dimensions of energy is $E = ML^2T^{-2}$

Solution:

Dimensions of the left hand side of the relation is ML^2T^{-2}

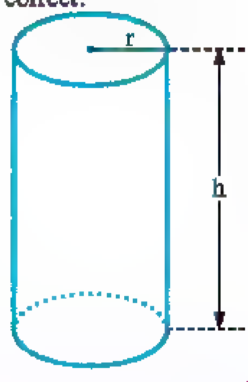
Dimensions of the right hand side: $\frac{1}{2}$ is a numeral having no dimensions

mass $\times$ square of velocity: $M(L/T)^2 = ML^2T^{-2}$

Therefore, KE $= \frac{1}{2}$ m v^2 is dimensionally correct because we have the same dimensions on both sides. .

Solved Example

Someone has suggested that the cylinder volume can be determined by the relation: $V = \pi rh$ Where (r) is its base radius and (h) is its height. Use the dimensional formula to show whether or not the relation is correct.



Solution:

Dimensions of the left hand side of the relation is L^3.

Dimensions of the right hand side: (π) has no dimensions

And, [r h] = length x length = L^2

Therefore, the relation is dimensionally wrong because different dimensions exist on both sides.

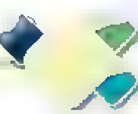
Note that having the same dimensions on both sides of a relation does not mean for sure that it is correct. On the other hand, different dimensions on both sides confirms that it is wrong.

Thinking Corner

The movement of an object by the effect of gravity is given by the relation:

$$v_f = v_i + gt$$

Verify this relation using the dimensional analysis; given that g is the acceleration due to gravity, v_f is the final velocity and v_i is the initial velocity.



Multiples and Fractions of Units in the International System

For measurement, the physical quantity is described by a numeral and a unit of measurement; for instance the distance between two stars is very vast and may be in the range of (100 000 000 000 000 000 m). On the other hand, the spacing among atoms in solids is estimated by nearly (0.000 000 001 m). No doubt, it is very difficult to read such values. Rather than that we prefer to express these values in the form of power of 10 The distance between two stars can be written as (1×10^{17} m) and the spacing among atoms in solids can be written as (1×10^{-9} m). This way of expressing the magnitude of physical quantities is known as "the standard formula". The factor $10^{\pm x}$ is given specific prefixes.

Factor	10^{-9}	10^{-6}	10^{-3}	10^{-2}	10^{3}	10^{6}	10^{9}
Prefix	nano	micro	milli	centi	kilo	Mega	Gega
Symbol	*n*	*μ*	*m*	*c*	*k*	*M*	*G*

Solved Example

An electric current has intensity 7 milliampere (7 mA). Express this intensity in microamperes.

Solution:

From the table above: 1 mA = 10^{-3} A

1 μA = 10^{-6} A

Dividing the two relations:

$$\frac{1\ mA}{1\ \mu A} = 10^{3}$$

1 mA = 10^{3} μA

Multiply both sides by (7): 7 mA = 7×10^{3} μA

This means that: 7 milliampere = 7000 microampere.

Measurement error

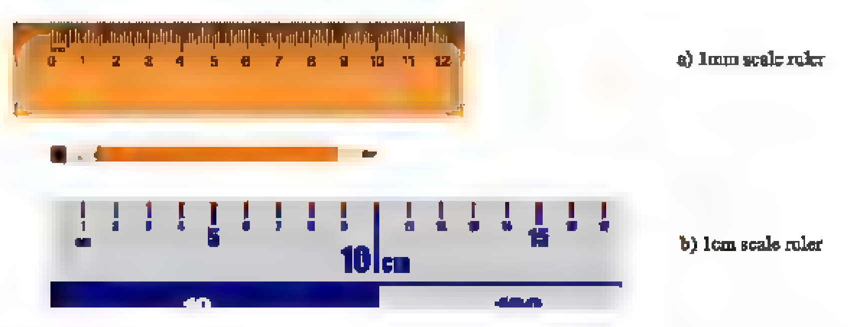
Man has been interested throughout history to improve procedures of measurement and develop instruments to achieve highly accurate measurements that have a great impact on the scientific and technological progress.

But, no measurement is accurate 100 %. There must be an error even if small. For example, when measuring the length of a room, a difference may be found between the measured value and the exact length. This difference could be small or big depending on the measurement procedure.

The teacher asked 5 students to measure the length of a pencil. The results were recorded as:

Student	First	Second	Third	Fourth	Fifth
Pencil length	*10.1 cm*	*10 cm*	*9.8 cm*	*10 cm*	*10.2 cm*

- What do you conclude through these records?
- Mention the possible reasons for these differences.
- Which ruler you think is better in measuring the pencil length? Why?



a) 1mm scale ruler

b) 1cm scale ruler

Reasons of measurement error:

There are several probable reasons for a measurement error, of these reasons:

Figure (7): An old-fashioned ammeter

1. **Choosing improper tool:** for example, using the beam balance instead of a sensitive balance in measuring the mass of a golden ring leads to a relatively big measurement error.

2. **A defect in the measuring tool:** the measuring tool may have one defect or more; an ammeter for example may:
   - Be old and the magnet inside is partially demagnetized.
   - The pointer has a zero error when no current flows through it; as seen in the opposite figure.

3. Wrong procedure: A lot of errors are caused by unexperienced persons. Of these errors:

- Ignorance of using the multimeters.
- Looking at the device pointer or the graduation scale at an oblique line. It is advisable to make the pointer or the scale divition lie in the plane of vision.

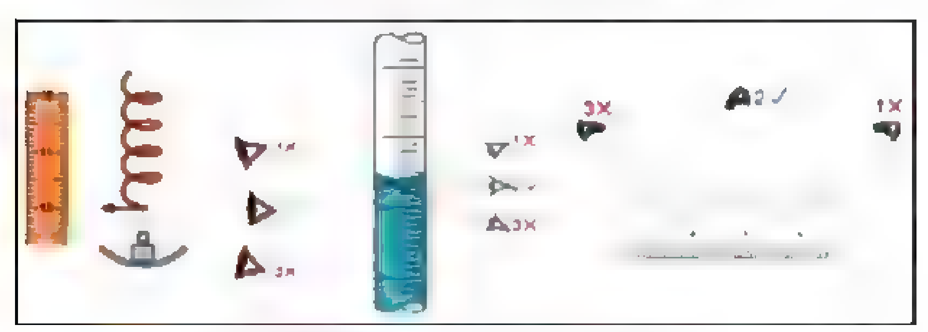


Figure (8): The vision plane should be perpendicular to scale

4. Environmental conditions: such as temperature, humidity or the air currents. When measuring the mass of a light object using the sensitive balance, the air currents may produce an error. Because of this the sensitive balance is kept inside a glass box.

Estimating error of measurement:

Before demonstrating how to estimate the error of measurement, we'd like to distinuish between two types of measurement:

1. Direct measurement: in which one measuring tool is used, for instance, the liquid density can be measured by the hydrometer.
2. Indirect measurement: in which more than one measuring tool are used, the liquid density can be determined via measuring mass by a balance and volume by a graduated cylinder. Then, dividing mass by volume.

Figure (10) measuring density indirectly using the balance and graduated cylinder may lead to two measurement errors

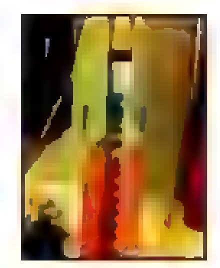
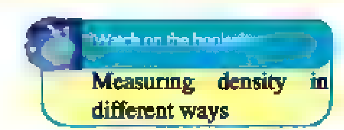


Figure (9) measuring density directly using the hydrometer may lead to one measurement error

Point of comparison	Direct measurement	Indirect measurement
Number of processes	one measurement process	More than one measurement process
Calculations	No mathematical relation is applied	A mathematical relation is applied to find the quantity
Measurement error	One measurement error	More than one measurement error " cumulative error"
Examples	Measuring volume using the graduated cylinder	Measuring volume by multiplying length, width and height

(1)- Estimating error in direct measurement:



The Absolute Error (Δx): is the difference between the actual value (x_0) and the measured value (x).

$\Delta x = |x_0 - x|$

The sign | | indicates that the result is always positive even if the actual value is less than the measured value. The most important thing here is to estimate the error whether it is an increase or a decrease in the real value. For example: $|-8| = 8$

The Relative Error (r): is the ratio between the absolute error (Δx) to the real value (x_0).

$$r = \frac{\Delta x}{x_0}$$

Solved Example

A student measured the length of a pencil. It was found to be 9.9 cm, meanwhile its actual length is 10 cm. Another student measured the classroom length. It was found to be 9.13 m, meanwhile its actual length is 9.11 m. Estimate both the absolute error and the relative error in each case.

Solution: **In case of the first student:**

Estimating the absolute error: $\Delta x = |x_0 - x| = |10 - 9.9| = 0.1\ cm$

Estimating the relative error: $r = \frac{\Delta x}{x_0} = \frac{0.1}{10} = 0.01 = 1\ \%$

In case of the second student:

Estimating the absolute error: $\Delta x = |x_0 - x| = |9.11 - 9.13| = |-0.02|\ m = 2\ cm$

Estimating the relative error: $r = \frac{\Delta x}{x_0} = \frac{0.02}{9.11} = 0.0022 = 0.22\ \%$

And we can express the result of measurement as follows:

The pencil length = $(10 \pm 0.1)\ cm$ And the classroom length = $(9.11 \pm 0.02)\ m$

Although the absolute error in measuring the classroom length is greater than that in measuring the pencil length, the relative error in measuring the classroom length is less than that in measuring the pencil length. This means that the accuracy in measuring the classroom length was relatively higher than measuring the pencil length.

Conclusion: The relative error is a better indication for the measurement accuracy than the absolute error. As the relative error decreases, the measurement accuracy is considered higher. .

(2)- Estimating error in case of indirect measurement:

The procedure of calculating error in case of indirect measurement depends on the mathematical operations applied:

Mathematical operation	Example	Finding the error
Summation	Measure the volume of two amounts of a liquid	The absolute error = the absolute error in first measurement + the absolute error in second measurement. $\Delta x = \Delta x_1 + \Delta x_2$
Subtraction	Finding the volume of a coin by subtracting the volume of water after and before dropping the coin into the measuring cylinder.	
Multiplication	Finding the area of a rectangle by measuring its length and width and multiplying them.	The relative error = the relative error in first measurement + the relative error in second measurement $r = r_1 + r_2$
Division	Finding the density of a liquid by measuring its mass and volume and dividing them.	

Solved Examples

Calculate each of the relative error and the absolute error when measuring the area of a rectangle (A) of length (6±0.1) m and width (5±0.2) m.

Solution:

The relative error in measuring length: $r_1 = \frac{\Delta x}{x_0} = \frac{0.1}{6} = 0.017$

The relative error in measuring width: $r_2 = \frac{\Delta y}{y_0} = \frac{0.2}{5} = 0.04$

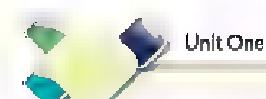
The relative error in measuring area: $r = r_1 + r_2 = 0.017 + 0.04 = 0.057$

Since r $r = \frac{\Delta A}{A_0}$

The absolute error (ΔA) is given by multiplying the relative error by the real area (A_0)

$$\Delta A = r \times A_0 = (0.057) \times (5\times6) = 1.7 \text{ m}^2$$

Therefor, the rectangle area can be estimated as $A = (30\pm1.7) \text{ m}^2$



In a lab experiment to determine a physical quantity (L) by adding two physical quantities L_1 and L_2 if:

$L_1 = (5.2 \pm 0.1)$ cm and $L_2 = (5.8 \pm 0.2)$ cm,

Find the value of L.

Solution:

Finding the real value of (L): $L_0 = (5.2+5.8) = 11$ cm

Finding the absolute error: $\Delta L = (0.1 + 0.2) = 0.3$ cm

$\therefore L = (11 \pm 0.3)$ cm

Calculate the relative error and the absolute error when measuring the volume or a cuboid where its dimensions are as follows:

Dimension	Measured value (cm)	Actual value (cm)
Length (x)	4.3	4.4
Width (y)	3.3	3.5
Height (z)	2.8	3

Solution:

First: estimating the relative error:

The relative error in measuring length: $r_1 = \frac{\Delta x}{x_0} = \frac{|4.4 - 4.3|}{4.4} = 0.023$

The relative error in measuring width: $r_2 = \frac{\Delta y}{y_0} = \frac{|3.5 - 3.3|}{3.5} = 0.057$

The relative error in measuring height: $r_3 = \frac{\Delta z}{z_0} = \frac{|3 - 2.8|}{3} = 0.067$

The relative error in measuring Volume:

$$r = r_1 + r_2 + r_3 = 0.023 + 0.057 + 0.067 = 0.147$$

Second: estimating the absolute error:

The real volume of the cuboid (V_0)

$$V_0 = x_0 y_0 z_0 = 4.4 \times 3.5 \times 3 = 46.2\ cm^3$$

$$r = \frac{\Delta V}{V_0}$$

$$\Delta V = r\, V_0$$

$$\Delta V = 0.147 \times 46.2 = 6.79\ cm^3$$

Activities and Exercises

Chapter One

Physical Measurements

Safety Rules

Expected Learning Outcomes

By the end of this activity you will be able to:
- Measure length precisely
- Identify tools of measuring length

Skills to be acquired
- Skills of measuring length.
- Skills of using the Vernier Caliper. (accuracy of 0.01 cm).

Tools and Materials

A metric ruler – A measuring tape – A Vernier Caliper – A glass slide – A pencil

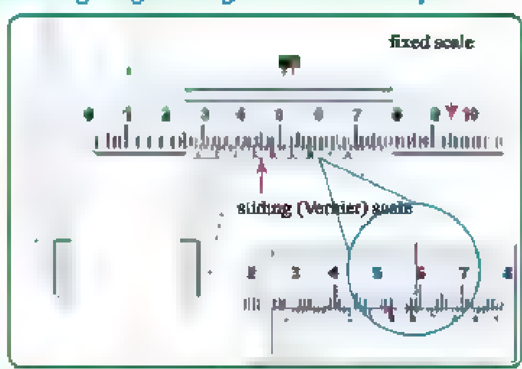
First- Practical Experiments

(1) Measuring lengths:

Experiment overview:

Man needs to measure different lengths. Some are long such as the length of a garden fence; others are short such as the thickness of a thin metallic sheet. Accordingly, different measuring tools are used to fit with each case.

Measuring length using the Vernier Caliper:



Calipers are comprised of two jaws, one attached to a fixed scale and the other attached to a sliding (vernier) scale. Divisions on vernier scale are slightly closer together than those on the fixed scale.

One division on the fixed scale represents 1 mm (one millimeter) while one division on the sliding scale represents 0.99 mm. It means that one division on the sliding scale is less than one division on the fixed scale by 0.01 mm. Accordingly, the vernier reading is found by multiplying the number of divisions by 0.1 mm.

Procedure:

1. The object is placed between the two jaws of the caliper and gently pressed.
2. Take the reading on the fixed main scale just before the zero mark of the sliding vernier scale lines up. Say, 28 mm.
3. Find the mark on the vernier scale that most closely lines up with one of the marks on the main scale. Say, the sixth line; thus we add ($6 \times 0.1 = 0.6$ mm) to the previous reading.

   The measured length becomes 28 mm + 0.6 mm = 28.6 mm

Measuring different lengths:

1. To measure the length of an object, you need to decide on the suitable measuring tool for such purpose.

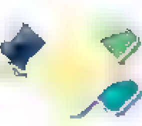
Put a tick (√) to select the proper tool for measuring each of the following lengths:

Measured Length	Measuring Tool		
	Vernier Caliper	Ruler	Measuring tape
Length of a classroom			
Width of a book			
Thickness of a glass slide			
Diameter of a pencil			

2. After selecting the proper tool, use it in measuring the length. It is advisable to repeat the procedure several times and calculate the average value aiming to obtain a highly accurate measurement.

Results:

Measured Length	Measuring Results			
	First Trial	Second Trial	Third Trial	Average value
Length of a classroom				
Width of a book				
Thickness of a glass slide				
Diameter of a pencil				



Safety Rules

Expected Learning Outcomes

By the end of this activity you will be able to:
- Determine the area of a circle.
- Determine the lateral surface area of a cylinder
- Determine the surface area of a cylinder precisely.

Skills to be acquired

- Skills of accurate measurement
- Skills of handling tools

Tools and Materials

A cylindrical can – Cardboard – A scissors – A graph sheet of paper A ruler

(2) Measuring the surface area of a cylinder:

Experiment overview:

A cylinder is an object of two identical circular bases, parallel to each other, while its lateral side is a curved surface called a cylindrical surface.

Determination of the surface area of a cylinder

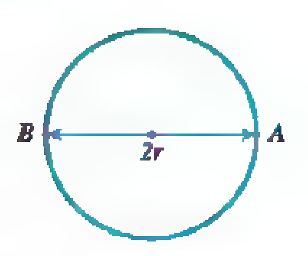
Assume that the radius of the cylinder base is (r) and its height is (h),

- Its base area $= \pi r^2$
- The lateral surface area = base circumference × height $= 2\pi rh$

(A) Determination of the area of the cylinder base:

Procedure:

1. Put the cylinder base on a graph sheet and mark its position with a pencil line.
2. Remove the cylinder and measure the diameter of its base (2r) by the ruler.
3. Calculate the radius (r), and then find the base area which is circular in shape (πr^2).



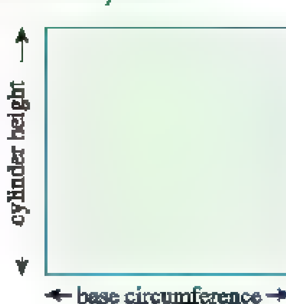
(B) Determination of the lateral area of the cylinder:

Procedure:

1. Measure the height of the cylinder (h).
2. Calculate the base circumference that equals $= 2\pi r$
3. **The lateral area** $= 2\pi r \times h$

(C) Another method to determine the lateral area of the cylinder:

Procedure:



1. Wrap the cardboard sheet around the cylinder exactly one complete turn.
2. Straighten the cardboard sheet to get a rectangle of length equal to the base circumference and width equal to the cylinder height.
3. Measure the length of this circumference.
4. Multiply the circumference length x height to obtain the lateral surface area of a cylinder.

Results:

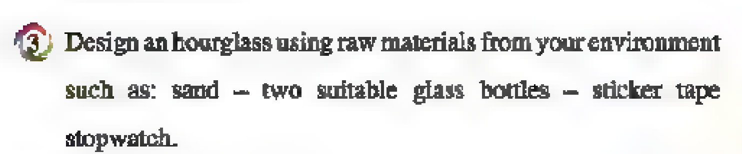
1. Diameter $= B2r =$ ....
2. Radius $= r =$ ....
3. Circumference length $= 2\pi r =$ ....

Result analysis:

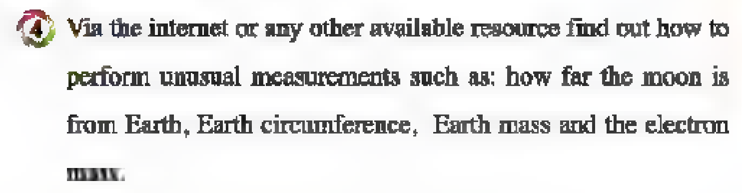
1. Base area $= \pi r^2 =$ ....
2. Cylinder height $= h =$ ....
3. Lateral area $= h \times 2\pi r =$ ....
4. Total surface area $= 2\pi r^2 + 2\pi rh =$ ....

Second – Evaluation Activities

1. Write a research provided with illustrative diagrams about some measuring tools in different historical eras including information about: structure – operation idea – usage.
2. Design and implement a beam balance using raw materials from your environment such as: thread – two metal cans – wooden rod – nails.



3. Design an hourglass using raw materials from your environment such as: sand – two suitable glass bottles – sticker tape – stopwatch.



4. Via the internet or any other available resource find out how to perform unusual measurements such as: how far the moon is from Earth, Earth circumference, Earth mass and the electron mass.

Third – Questions and Exercises

1. What is the difference between the fundamental physical quantity and the derived physical quantity?

2. Express the following values using the standard formula in writing numerals:
   a. The elephant mass = *5000 kg*
   b. Speed of light through space *c* is about *300000000 m/s*

3. Define each of: the standard length, the standard mass, and the standard time.

4. Complete the blanks in the table:

The physical quantity	Unit of measurement	The dimensional formula
Velocity		
	m/s^2	
		MLT^{-2}
Density		

5. Given that work $= \frac{1}{2} mv^2$, deduce the dimensions of work.

6. Mention the precautions you may consider when using the metric ruler to measure the length of an object.

7. Express the following values in terms of the given unit using the standard formula in writing numerals.
   a. mg in kilograms.
   b. 3×10^{-9} s in milliseconds.
   c. 88 km in meters.

(8) If the diameter of man's hair is about 0.05 mm. find that diameter in meters.

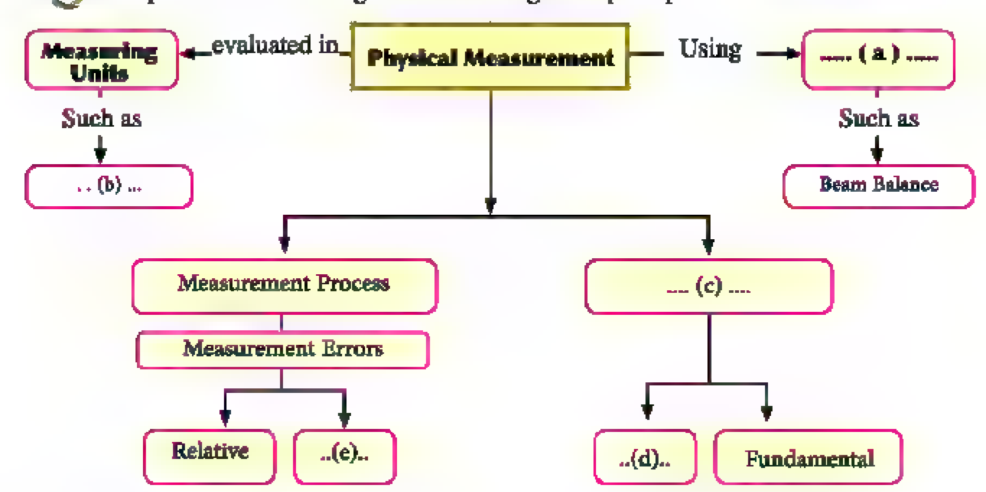
....

(9) An object of mass 4.5 kg ± 0.1 kg is moving at velocity 20 m/s ± 1 m/s Calculate the error in measuring its linear momentum. (linear momentum = mass x velocity)

....

....

(10) Complete what is missing in the following concept map:



(11) Enjoy crosswords.

Across

(3) The distance between two engraved marks at the ends of a rod made of platinum and Iridium alloy kept at 0°C.

(4) A physical quantity that can be defined in terms of the fundamental physical quantities.

(6) A physical quantity that cannot be defined in terms of other physical quantities

Down:

(1) The mass of a cylinder made of platinum and Iridium alloy of specific dimensions at the International Bureau of Weights and Measures

(2) Comparing a physical quantity with another quantity of its kind to find out how many times the first includes the second.

(5) A part of 86400 of the average solar day

Chapter Two

Scalar quantities & Vector quantities

Expected Learning Outcomes

By the end of this chapter you will be able to:

- Differentiate between the scalar and vector physical quantities.
- Perform scalar (dot) product of vector quantities.
- Perform vector (cross) product of vector quantities.

Physical Terminology

- *Scalar quantity*
- *Vector quantity*
- *Distance*
- *Displacement*
- *Scalar Product (Dot Product)*
- *Vector Product (Cross Product)*

Learning Resources

- **E- site:**
  scalar and vector physical quantities.
  http://www.engaswan.com/15695-topic

If we are informed that the temperature of a body is 37°C, it is a full piece of information. But, if we are reported that a car moves at 50 km/h, although the magnitude and the measuring unit have been given, we still wonder about the direction of the car motion. Is it to East, West or any other direction?

When expressing that the car moves at 50 km/h to east, this gives a full idea about the velocity of the car that includes magnitude and direction. Because of this, velocity is a vector quantity.

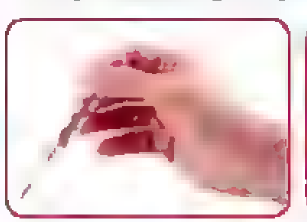


Figure (11): temperature is defined fully by its magnitude only

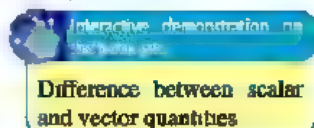
Figure (12): velocity is defined fully by its magnitude and direction.

Accordingly, physical quantities can be classified as:

- **A scalar quantity:** which is a physical quantity that can be fully defined by its magnitude only. It has no particular direction.

  Examples are: distance, mass, time, temperature and energy.

- **A vector quantity:** which is a physical quantity that can be fully defined by both magnitude and direction. Examples are: displacement, velocity, acceleration, and force.



Difference between scalar and vector quantities

1- Distance and Displacement

Distance is defined as the length of the path moved by an object from a position to another. Distance is a scalar quantity that can be fully defined by its magnitude only, and the link below shows the concept of the displacement :

Figure (13): The difference between distance and displacement

Displacement is the change in the position of an object. It is given by the length of the straight line segment in a given direction between the starting point and the end point.

Solved Example

An athlete has moved to West through a displacement of (50 m), then moved back to Eest through a displacement of (30 m). Calculate the distance covered and the displacement of the athelet.

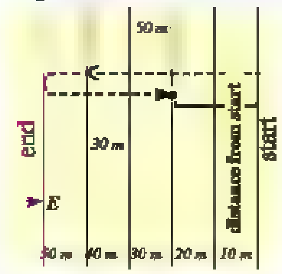


Figure (14): path of athlete movement

Solution

First: the covered distance: : $s = 50 + 30 = 80\ m$

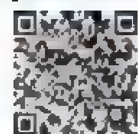
Second: the displacement of the athelet:

$d = +50 - 30 = +20\ m$

Displacement to west is considered positive and negative to east. The result shows that the athlete is displaced 20 m to west.

2- Representing vector quantities

The link below illustrates how to represent a vector quantity.



The vector is represented by a directed straight segment of length proportional to the vector mangnitude, pointing from the initial point to the end point. The vector is denoted by a bold letter (**A**) or a letter tagged by a small arrow ($\vec{A}$).

Graphical Representation of Vectors

The vector is represented by an arrow drawn at a suitable scale where:

- The arrow length represents the vector magnitude.
- The arrow direction represents the vector direction.

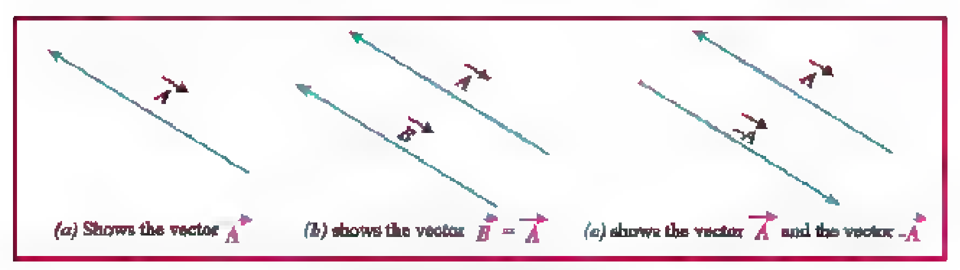


Figure (16): vector representation

Some basics of vector algebra:

1. Two vectors are considered equal if they have the same magnitude and direction even if each has a different initial point.
2. The magnitude of the vector $\vec{A}$ is equal to that of vector $-\vec{A}$, but having an opposite direction. What is the result if the vector is multiplied by (-1) ?

Resultant of vector addition:

To which direction an object would move when two forces or more act on it? What is the magnitude of the force that moves it?

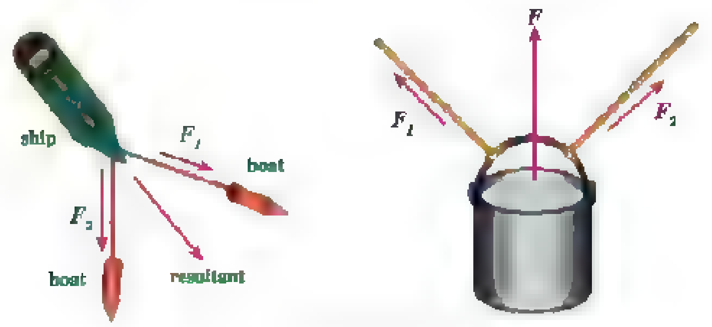


Figure (17): the resultant of two forces

The net force that affects an object as a result of the action of a number of forces is called the resultant force whose direction is that of the object motion.

The resultant force: is a single force that results in the same effect on the object as that produced by the original acting forces.

Generally, adding two vectors can be operated by either:

- Drawing a triangle as that shown in (figure 18b)
- Drawing a parallelopoid in which A and B are adjacent sides. Thus, the diagonal represents their resultant as in (figure 18c)

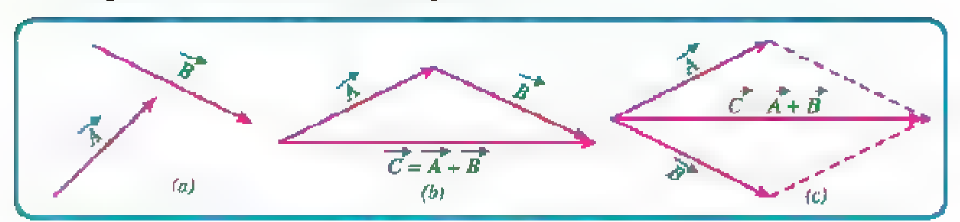


Figure (18): addition of vectors

Life Applications

Determine the direction of the resultant of the two forces F_1 and F_2 in each illustrated situation Knowing that they are equal. Assume that a third force which is equal and opposite to this resultant force acts on the same object, would the object move? Why?

Solved Example

Find the resultant of two forces; one of them ($F_x = 4$) acting in (x) dimension, while the other ($F_y = 3\ N$) acting in (y) dimension.

Solution:

We would comlete the shape of the parallelogram. A rectangle is formed since the two forces are perpendicular to each other. Thus, the diagonal represents the resultant force F as shown.

Applying Pythagoras theorem, the magnitude of the resultant F is given by:

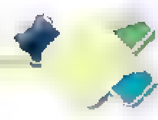
$$F^2 = F_x^2 + F_y^2 = 16 + 9 = 25$$

$$\therefore F = \sqrt{F_x^2 + F_y^2} = \sqrt{25} = 5\ N$$

$$\tan\theta = \frac{F_y}{F_x} = \frac{3}{4}$$

$$\therefore \theta = 36.87^\circ$$

(Finding the resultant of two forces)



ReSolution of a Vector

Resolving a vector is a reverse operation for the process of getting the resultant of some vectors. In the following diagram, a girl drags another by a rope in a direction makes an angle(θ) to the horizontal. Resolving the force (F) into two perpendicular forces along dimentions (x , y) consequently:

$$F_x = F \cos \theta \qquad F_y = F \sin \theta$$

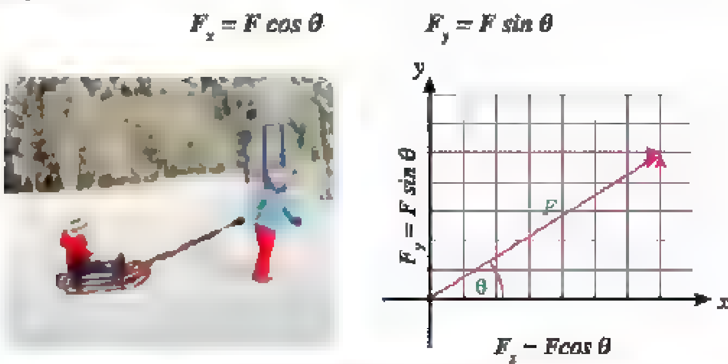


Figure (19): ReSolution of force

3- Product of vectors

There are different forms of finding the product of two vectors:

First: Scalar (Dot) product

The dot product of two vectors $\vec{A}$ and $\vec{B}$ gives:

$$\vec{A} . \vec{B} = A\,B \cos \theta$$

The result is a scalar quantity equal to the product of the magnitudes of (A) and (B) and the cosine of the angle between the two vectors ($\cos \theta$). The point between the two vectors sounds "*dot*".

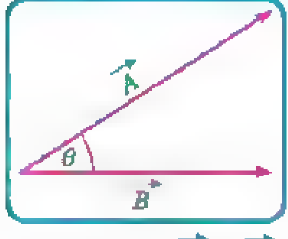


Figure (20): vectors $\vec{A}$ and $\vec{B}$

Second: Vector (Cross) product:

The cross product of two vectors $\vec{A}$ and $\vec{B}$ equals:

$$\vec{C} = \vec{A} \wedge \vec{B} = AB \sin \theta \, \vec{n}$$

The result is a vector quantity ($\vec{C}$) whose magnitude is equal to the product of the magnitudes of (A) and (B) and the sine of the angle between the two vectors. The sign (^) between the two vectors sounds "cross"

Where $\vec{n}$ is a unit vector directed in a direction perpendicular to the plane of both vectors $\vec{A}$ and $\vec{B}$.

This direction that represents the direction of the resultant vector $\vec{C}$ can be defined by **"the right hand rule"**. Figure (21)

Applying the right hand rule:

Move the fingers of the right hand from the first vector towards the second vector through the smaller angle between them, the thumb then points to the direction of the resultant vector.

It is worthy to mention that:

- θ lies between $\vec{A}$ and $\vec{B}$
- $\vec{A} \wedge \vec{B} \neq \vec{B} \wedge \vec{A}$
- $\vec{A} \wedge \vec{B} = -\vec{B} \wedge \vec{A}$

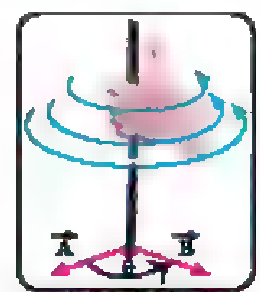


Figure (21) the right hand rule to define the direction of the resultant of cross product of two vectors

Solved Example

If the magnitudes of two vectors $\vec{A}$ and $\vec{B}$ are 5 and 10 respectively and the angle between them is 60°, find the result of each of:

First: $\vec{A} \cdot \vec{B}$ Second: $\vec{A} \wedge \vec{B}$

Solution:

First:

$\therefore \vec{A} \cdot \vec{B} = AB \cos\theta$

$\therefore \vec{A} \cdot \vec{B} = 5 \times 10 \times 0.5 = 25$

Second:

$\vec{C} = \vec{A} \wedge \vec{B} = AB \sin\theta \, \vec{n} = (5 \times 10 \times 0.866) \, \vec{n}$

$\vec{C} = 43.3 \, \vec{n}$

$\vec{C}$ is the resultant vector having a magnitude 43.3 and direction perpendicular to the plane of both vectors $\vec{A}$ and $\vec{B}$.

Field Visit:

Hallmark and balances department (bureau) is considered as an expert office in Egypt to assay and calibrate weighing scales, measuring tools and bushels. It is also concerned with supervision and inspection. It has 54 branches allover the country.

You may visit either one of these branches in your governorate or The National Institute of Measurement and Calibration in Giza that develops the national standards of physical measurements, keeping it up with the international standards.

Activities and Exercises

Chapter Two

Scalar and Vector Quantities

Safety Rules

Expected Learning Outcomes

By the end of this activity you will be able to:

- Find the resultant of two forces.

Skills to be acquired

- Skills of using geometrical sets.
- Skills of representing the resultant of two forces and finding its magnitude.

Tools and Materials

A graph sheet of paper
A compass – A protractor – A ruler

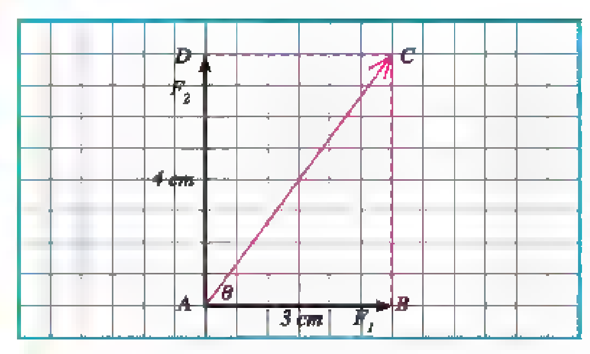
First- Practical Experiments

Finding the resultant of two forces:

Find the resultant of the two perpendicular forces: $F_1 = 3\,N$

$F_2 = 4\,N$

Procedure:



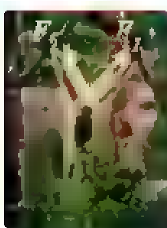
1. Draw a horizontal line (AB) on the graph paper of length 3 cm to represent the first force.
2. Draw a vertical line (AD) perpendicular to (AB) at the point (A) of length 4 cm to represent the second force.
3. Complete the rectangle.
4. Join the diagonal (AC) to represent the magnitude and direction of the resultant.
5. Measure the length of the line segment (AC). It represents the magnitude of the resultant force.
6. Measure the angle (BAC) that defines the direction of the resultant force relative to the first force (F_1).

7. Find the magnitude of the resultant force using Pythagoras' theorem for the right angled triangle: ($AC^2 = AB^2 + BC^2$)

$$F^2 = F_1^2 + F_2^2$$

8. Compare the two results of the resultant force.

Second - Evaluation Activities


What forces act on this creature?

1. Prepare a photo album to clarify the effect of a group of forces on different objects. Cooperate with your colleagues to determine the resultant force in each photo.
2. Write down a list for the scalar and vector quantities commonly dealt with in our daily experience.
3. Write down a research about the importance of mathematics in the study of physics, having the topic of dot product and cross product as an example.

Third - Questions and Exercises

1. What is the difference between the scalar quantity and the vector quantity?

....

....

2. What is meant by saying that the displacement of a car to north is ($500\ m$)

....

....

3. Find the dot product and the cross product of two vectors $\vec{AB} = 8\ N$, $\vec{AD} = 6\ N$ given that the angle between them ($\theta = 45^\circ$)

....

....

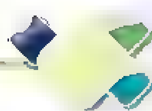
4. Use the ruler and protractor to find the resultant of two vectors; the magnitude of the first (3cm) while the other (4cm) and the angle between their directions (°115)

....

....

....

....



(5) When is the vector summation of a number of vectors equal to zero?

....

....

....

(6) When is the difference between two vectors equal to zero?

....

....

....

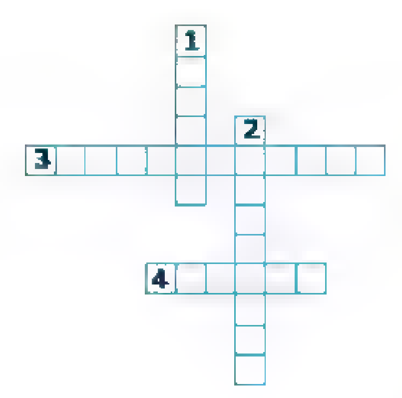
(7) When is the dot product of two vectors equal to zero?

....

....

....

(8) Enjoy crosswords:



Across

(3) The straight line segment in a certain direction between a starting point and end point

(4) A physical quantity that can be fully defined by its magnitude and direction

Down

(1) A physical quantity that can be fully defined by its magnitude only

(2) A single force produces the same effect on an object as that produced by a number of forces acting on it.

General Exercise on the First Unit

1 Choose the correct answer for each phrase of the following:

a. A derived quantity of the following is ....

(length – mass – time – velocity)

b. In the international system of units, the ampere is the unit of the ....

(electric current intensity – electric charge – length – luminous intensity)

c. Dimensions of acceleration are ....

$(LT - LT^{-1} - LT^{-2} - L^2T^{-1})$

2 Write the dimensions of each of: Force – Work – Pressure (equals force by area).

3 Express the following values using the standard formula in writing numerals:

a. The radius of Earth $= 6000000\ m$

b. The radius of the hydrogen atom $= 0.00000000005\ m$

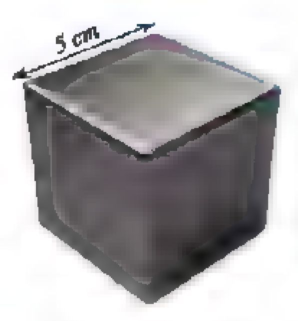
4 What is the difference between the concepts of distance and displacement? Give an example.

5 Find the distance and displacement of an object when moving along the circumference of a circle of radius 7 m from (A) to (B). Then, find the distance and displacement when it returns to (A) another time.

6 Find the magnitude and direction of the resultant of two perpendicular forces (F_1 and F_2) Where:

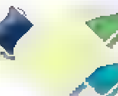
$F_1 = 3\ N \qquad F_2 = 4\ N$

Illustrate your answer by drawing vectors.



7 Find the relative error in estimating the volume of a cube of side length 5 cm given that the relative error in estimating its length is (0.01 cm). Also, find the absolute error in this case.

8 State the precautions considered when using the meter ruler to measure the length of an object.



9. A student wrote in a physics test the following relation:
(velocity in m/s = acceleration in m/s^2 × time in s). Use the dimensional formula to verify this relation

10. Einstein has formulated his famous law: $E = m c^2$, where (c) is the speed of light and (m) is the mass. Use this law to derive the international (SI) unit of the quantity (E)

11. Apply the dimensions of physical quantities to verify the relation: $v_f^2 = v_i^2 + 2\,a\,d$
Where (d) is the displacement of an object moving at initial velocity (v_i) and speeds up regularly at an acceleration (a) till it reaches a final velocity (v_f)

12. $\vec{A}$ and $\vec{B}$ are two vectors having an angle °120 between them where the magnitude of ($\vec{A}$) = 3 units and the magnitude of ($\vec{B}$) = (4) units. Find:

a. Their dot product. b. Their cross product.

13. Knowing that the radius of the planet Saturn = 5.85×10^7m and its mass 5.68×10^{26}kg

a. Find the average density of the planet materials in g/cm^3.

b. Calculate the surface area of the planet in m^2 (Consider surface area = $4\,\pi\,r^2$)

14. A ship sails to North at velocity 12 km/h. Due to tides, it is deviated to West at velocity 15 km/h . Find the magnitude and direction of the resultant velocity of the ship.

15. A motorcyclist drove to North at velocity 80 km/h. Meanwhile wind was blowing towards West at velocity 50 km/h. Calculate the apparent velocity of wind as observed by the motorcyclist.

16. If $y = (10 \pm 0.2)$ *cm* , and $x = (5 \pm 0.1)$ *cm* , find each of:

a. $x + y$ b. $2x + y$ c. xy d. xy^2

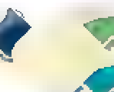
In a nutshell

First: Main Concepts

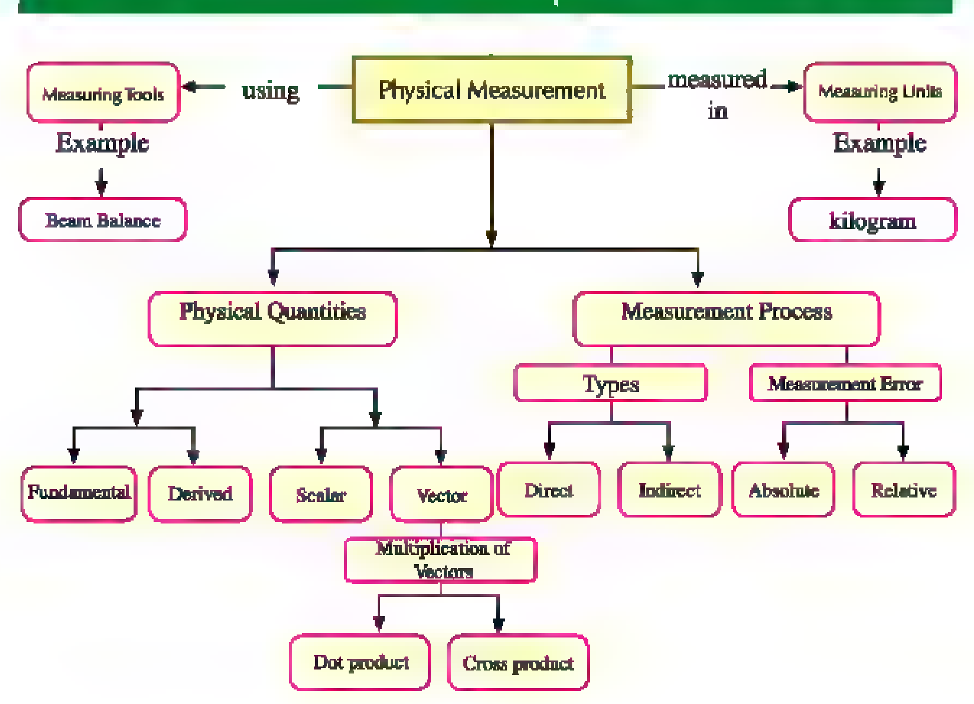
- **Measurement :** Measurement is comparing a physical quantity with another quantity of its kind to find out how many times the first includes the second.
- **The Absolute Error:** is the difference between the actual value and the measured value.
- **The Relative Error (r):** is the ratio between the absolute error to the real value of the measured physical quantity
- **A scalar quantity:** a physical quantity that can be fully defined by its magnitude only, such as distance, time, and temperature.
- **A vector quantity:** a physical quantity that can be fully defined by its magnitude and direction Examples are: displacement, velocity, acceleration, and force.

Second: Main Relationships.

- **The dot product** of two vectors $\vec{A}$ and $\vec{B}$: $\vec{A} \cdot \vec{B} = A\,B \cos\theta$ where θ is the angle between them.
- **The cross product** of two vectors $\vec{A}$ and $\vec{B}$: $\vec{A} \wedge \vec{B} = \vec{C} = AB \sin\theta\ \vec{n}$ where $\vec{n}$ is a unit vector directed in a direction perpendicular to the plane of both vectors $\vec{A}$ and $\vec{B}$.



Mind Map


Physical Measurement
using
Measuring Tools
Example
Beam Balance
measured in
Measuring Units
Example
kilogram
Physical Quantities
Measurement Process
Types
Measurement Error
Fundamental
Derived
Scalar
Vector
Direct
Indirect
Absolute
Relative
Multiplication of Vectors
Dot product
Cross product

UNIT TWO

Linear Motion

Unit Chapters

Chapter One : Motion in a straight line.

Chapter Two : Motion at uniform acceleration.

Chapter Three : Force and Motion.

Unit Introduction

UNIT OBJECTIVES

By the end of this unit, you would be able to:

- Define the concept of motion in a straight line
- Identify the types of motion.
- Plot and explain the different graphs that represent the relationships: (displacement – time) and (velocity – time)
- Differentiate and compare the types of velocity.
- Deduce the equations of motion at uniform acceleration.
- Inquire, analyze, and explain the graphical representations related to linear motion.
- Identify the motion of objects under free fall.
- Conclude the motion in two dimensions such as projectile motion.
- Design an experiment to determine the free fall acceleration.
- Apply the relation between force, mass and acceleration.
- Explain the action – reaction pairing.

- Appreciate the efforts of Galileo and Newton in formulating the laws of motion
- Acquire awareness of the dangers of reckless driving.
- Admire the role of science and technology in kinematics study and development of transportation

- Scientific interpretation.
- Draws a conclusion
- Comparison.
- Classification .
- Application

Chapter One

Motion in a Straight Line

By the end of this chapter you will be able to:

- Define the concept of motion in a straight line.
- Identify the types of motion.
- Plot and explain the different graphs that represent the relationships (displacement – time) and (velocity – time).
- Differentiate and compare the types of velocity.
- Inquire, analyze, and explain the graphical representations related to linear motion.

Physical Terminology:

- *Motion*
- *Speed.*
- *Velocity.*
- *Uniform velocity.*
- *Instantaneous velocity*
- *Acceleration.*

- Educational video: Calculating velocity using the relation between (displacement – time)
http://www.youtube.com/watch?v=SkWFD_F3j04

Objects around us can be sorted into stationary objects and moving objects. As we study the motion of different objects, it is necessary to describe and understand such motion. The vague ideas about motion convert travelling by ships, trains and planes into a mess. Schedules of departure and arrival of different transportations are mainly based on distances, times and speeds.

Accordingly, in this chapter we are going to investigate the concept of motion and the related physical quantities.

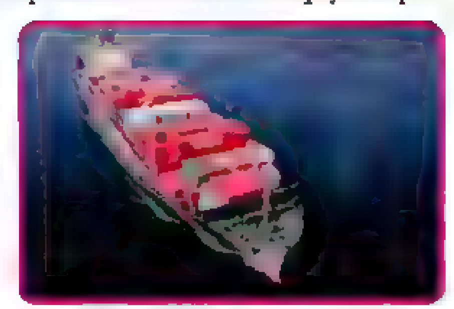


Figure (1): the effect of studying motion on transportation means.

Motion

The following sequence of photos illustrates the positions of a rat at equal intervals of time. Is this rat moving or stationary?

Figure (2): the position of the rat changes over time

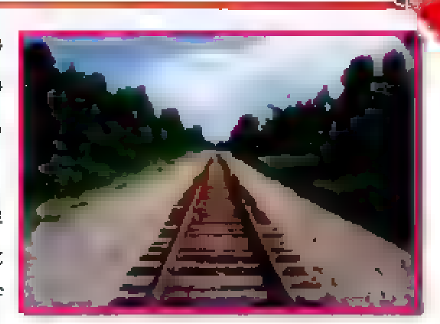


Figure (2-3): the train motion is a good example for the motion in a straight line. In many regions rails are straight for a long distance.

Motion: is the change in the position of the object with respect to a fixed point as the time passes. Obviously, an object moves when its position changes during an interval of time.

If this motion is in one dimension along a straight path, it is then called motion in a straight line which is considered the simplest type of motion.

Extra knowledge

Motion diagrams: the motion of an object can be represented by a series of photos taken in equal intervals of time. The pattern that represents the sequence of motion is called the "motion diagram".

Types of Motion:

Motion can be categorized into two main types: translational motion and periodic motion.

Figure (4): translational motion

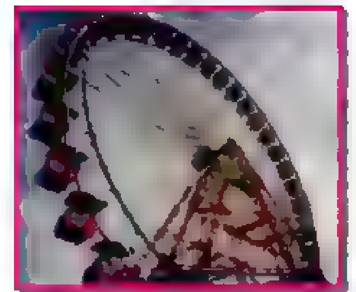


Figure (5): periodic motion

- **Translational motion:** is the motion which is characterized by having a starting point and end point. Examples are motion in a straight line, and projectile motion.
- **Periodic motion:** is the motion that repeats itself over equal intervals of time. Examples are motion in a circle and vibrational motion.

Science Processes

Classify the motion of the following objects into either translational or periodic :

- Clock Pendulum
- Projectiles
- Trains
- The prongs of the tuning fork

2- Velocity

Moving objects are described as being slow or fast. Scientifically this is not fairly accurate. We can describe the object motion quantitatively through the concept of velocity.

To identify this concept, study the following motion diagram for athlete displacements every one second.

Figure (5): Motion diagram of an athlete

Through this diagram, the relation between displacement and time are recorded in the table below:

Time (s)	0	1	2	3	4	5	6
Displacement (m)	0	5	10	15	20	25	30

Using this table we can draw a conclusion that the athlete displacement is (5 *m*) every second. This quantity is known as velocity (*v*) that can be found by the relation:

$$\text{Velocity} = \frac{\text{Change of displacement}}{\text{Time of change}} \quad , \quad v = \frac{\Delta d}{\Delta t}$$

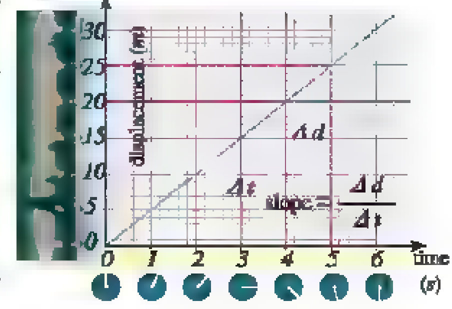
Applying this relation on the above mentioned example:

$$v = \frac{\Delta d}{\Delta t} = \frac{d_2 - d_1}{t_2 - t_1} = \frac{10 - 5}{2 - 1} = \frac{5}{1} = 5\ m/s$$

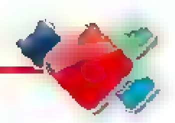
Velocity: **the displacement moved by the object in one second, or the rate of change of displacement. It is measured in (*m/s*) or (*km/h*).**

Graphical representation of the relationship between displacement and time:

Displacement is represented on the ordinate (y-axis) and time on the abscissa (x-axis):



- Draw a vertical line starting from the point (*1s*) on time axis.
- Draw a horizontal line starting from the point (*5 m*) on displacement axis.
- Highlight the point of intersection of the two lines.
- Repeat with the other points of time and displacement.
- Draw a straight line passing through most of the highlighted points.
- Calculate velocity by getting the (*slope*) of the straight line.

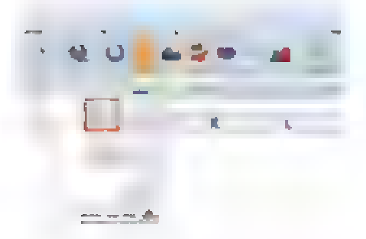


e- Learning Resources

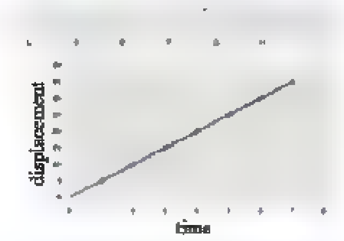
Graphical representation of the (displacement – time) relationship using the computer:

(1) Open *excel* program, choose insert datasheet

(2) Inter data: time in the first column, and displacement in the second column. Then, select data.



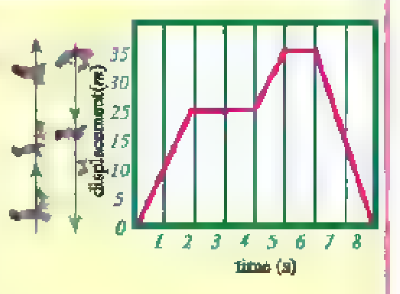
(3) Choose insert. Then, choose the graph in red.



(4) A line appears on the screen. Find the velocity using the line slope.

Thinking Corner

The opposite graph represents a walk of a girl from her house and returning back again. Study the graph and answer the questions :



- When did the girl stop walking?
- What is the maximum velocity of the girl motion?
- Why is her velocity when moving back considered negative?
- What is the difference between displacement and distance moved by the girl?

Types of velocity:

(A) Speed and Velocity :

Focusing on the speedometer of a car, its pointer swings right and left during car movement. The pointer reading specifies the value of the car speed (for example, $80\ km/h$) without defining the direction of the car motion. This value is known as (*Speed*).

Figure (7): Does the speedometer read speed or velocity?

However, just saying that a car moves at *80 km/h* is an incomplete description since no hint is given about the direction of the car motion. Accordingly we need to define such direction to give a full description for the car motion. For instance, saying that the car moves at *80 km/h* to East. in this case, we call this (*Velocity*).

Point of comparison	Speed	Velocity
Definition	The distance moved by the object per unit time.	The displacement of the object per unit time.
Its type	Scalar, defined by its magnitude only.	Vector, defined by its magnitude and direction.
Its sign	Always positive.	Positive in one direction and negative in the opposite direction.

It is worthy to mention that we are interested in velocity rather than speed when discussing the next texts, equations and problems since it offers a full description of motion.

(B)Uniform and Variable Velocity

As an athlete runs at uniform velocity, his displacements are equal in equal times. But if he moves at non uniform velocity, his displacements are unequal in equal times.

Uniform velocity. the object velocity when it is displaced through equal displacements in equal times. Both the velocity magnitude and direction are constant (when the object moves in a straight line).

Non-uniform velocity: the object velocity when it is displaced through unequal displacements in equal times. Its velocity may change in magnitude or direction.

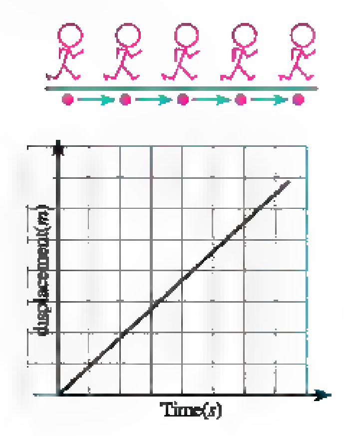


Figure (8): motion at uniform velocity

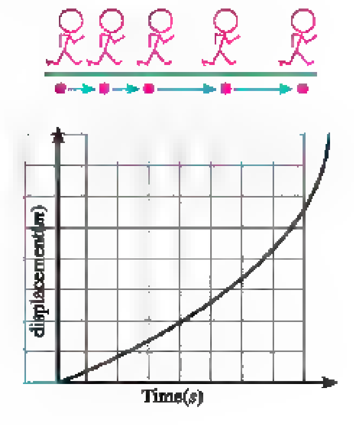
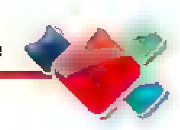


Figure (9): motion at variable velocity

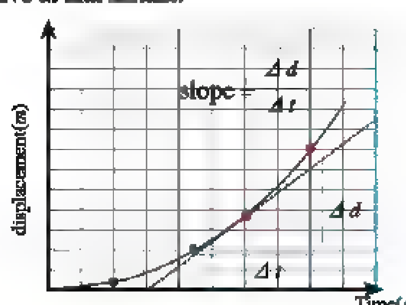


(C)Instantaneous and Average Velocity

The motion of a car on roads is certainly variable. The car speeds up or slows down responding to the traffic conditions. Consequently, we are going now to distinguish between the Instantaneous Velocity and Average Velocity of the object (car).

Instantaneous Velocity (v): The velocity of the object at a given instant. For example, the reading of the speedometer pointer at a given instant.

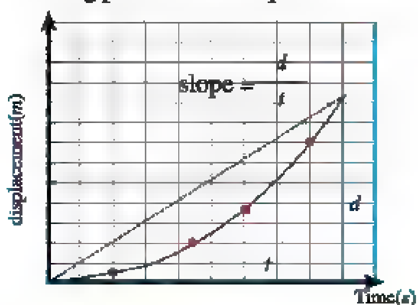
It can be determined graphically by the slope of the tangent drawn to the velocity curve at that instant.



$$\text{Instantaneous velocity } (v) = \frac{\text{Change of displacement } (\Delta d)}{\text{Time of change } (\Delta t)}$$

Average Velocity ($\bar{v}$): It is given by dividing the total displacement of the object from the starting point to the end point by the total time of motion.

It can be determined graphically by the slope of the straight line joining the starting point to the end point.



$$\text{Average velocity } (v) = \frac{\text{Total displacement } (d)}{\text{Total Time } (t)}$$

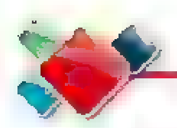
Correcting misconceptions

- One of the common misconceptions is the confusion between average velocity which is a vector quantity and average speed which is a scalar quantity:

$$\text{Average velocity} = \frac{\text{Total displacement}}{\text{Total Time}} \qquad \text{Average speed} = \frac{\text{Total distance}}{\text{Total Time}}$$

Time management:

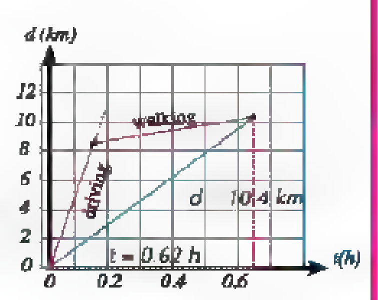
- Set a target for each task you are going to accomplish. Examine your targets. Are they realistic or not? Decide what you want to achieve and why.
- Design your daily or weekly schedule to arrange your activities and define deadlines. Keep a memo or reminder to record activities, dates and duties.



Solved Examples

Determination of the velocity of an object

1 A person drove a car in a straight line to cover (*8.4 km*) in (*0.12 h*). Because the fuel had run out, he walked through (*2 km*) along the same straight line to reach the nearest gas station after (*0.5 h*). Calculate the average velocity of this journey



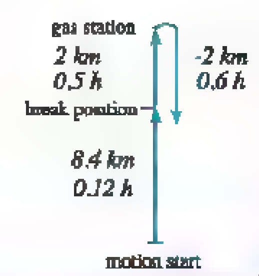
Solution:

$$\text{Average velocity} = \frac{\text{Total displacement } (d)}{\text{Total Time } (t)}$$

$$v = \frac{d}{t} = \frac{8.4 + 2}{0.12 + 0.5} = \frac{10.4}{0.62} = 16.8 \text{ km/h}$$

We can get the same result by finding the slope of the straight line joining the starting point to the end point.

If the person in the previous example returned back to his car in *0.6 h*, find the average velocity during the whole story.



Solution:

The total displacement = (*8.4 km*)

$$v = \frac{d}{t} = \frac{8.4}{0.12 + 0.5 + 0.6} = \frac{8.4}{1.22} = 6.88 \text{ km/h}$$

3-Acceleration

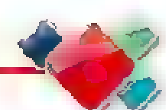
We have discussed the concept of the variable velocity (magnitude, direction or both) Motion in which velocity changes with time is called the accelerated motion and the quantity that expresses the change of velocity per unit time is called acceleration (*a*).

Speeding up at the start

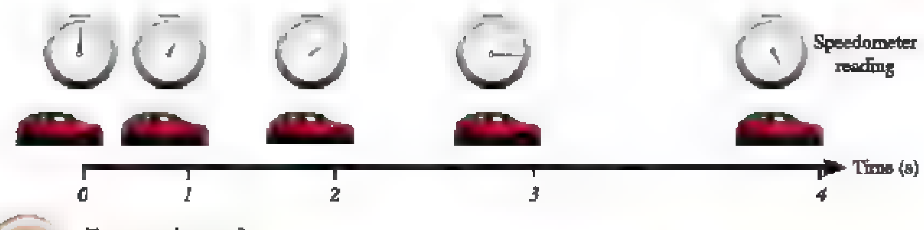
direction of velocity changes in curves

slowing down at the end

Figure (8): the term acceleration is used to express the change of velocity over time



To investigate the concept of acceleration, study the following motion diagram that illustrates the readings of the speedometer of a car moving from rest and speeds up in a straight line.



Do you know?

You can convert the speedometer reading from *km/h* into *m/s* by the relation:

$$\therefore 1\ km/h = \frac{1\ km}{h} = \frac{1000\ m}{60 \times 60\ s} = \frac{5}{18}\ m/s$$

Recording the data of the given diagram that include velocity (*m/s*) and time (*s*), we obtain the table below:

Time (*s*)	0	1	2	3	4
Velocity (*m/s*)	0	5	10	15	20

It is obvious that the car speeds up at a constant rate where its velocity increases by (*5m/s*). every second. This value expresses the acceleration of motion that can be found by the relation:

$$\text{Acceleration} = \frac{\text{Change of velocity}}{\text{Time of change}} = \frac{\text{Final velocity} - \text{initial velocity}}{\text{Final time} - \text{initial time}}$$

$$a = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1}$$

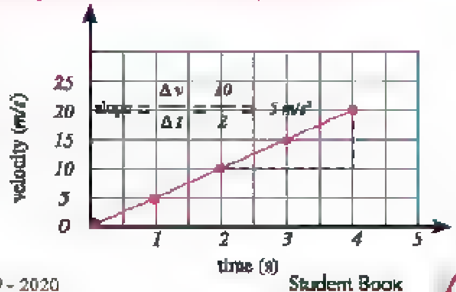
Applying this relation on the above mentioned example:

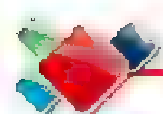
$$a = \frac{\Delta v}{\Delta t} = \frac{10 - 5}{2 - 1} = 5\ m/s^2$$

Acceleration: the change of the object velocity per unit time, or the rate of change of velocity. It is measured in (m/s^2) or (km/h^2).

Graphical representation of the relationship between velocity and time:

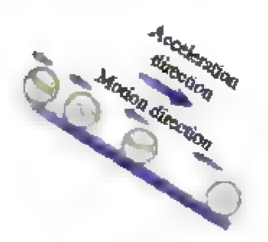
The graph (velocity – time) expresses the motion of the car in the previous motion diagram. Notice that a straight line is obtained indicating that the velocity of the car increases uniformly, and acceleration can be found by the slope of the straight line.



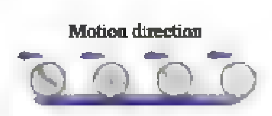


Types of Acceleration:

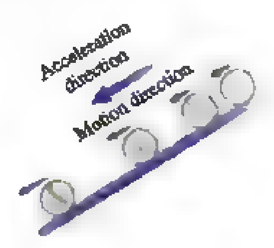
Objects may move at positive acceleration (increasing velocity), negative acceleration or deceleration (decreasing velocity) or zero acceleration (uniform velocity). These types can be identified by studying the following motion diagram that shows the motion of a small ball along frictionless planes of different inclination.



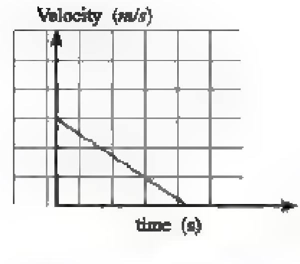
As the ball climbs up the inclined plane, its velocity decreases with time and acceleration is negative



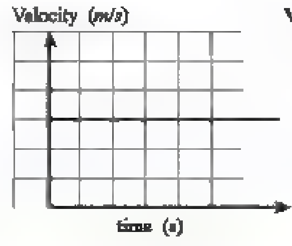
As the ball moves along the smooth horizontal plane, its velocity does not change with time and acceleration equals zero



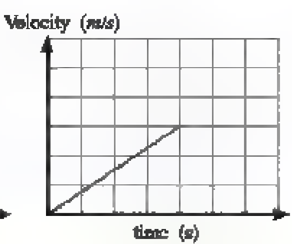
As the ball rolls down the inclined plane, its velocity increases with time and acceleration is positive



negative acceleration



zero acceleration



positive acceleration

Life Applications

- Three tools in the car can control the magnitude or the direction of the car velocity. These are the accelerator to pump more fuel, the brakes to slow down and the steering wheel to change direction.

Activities and Exercises

Chapter One

Motion in a Straight Line

Safety Rules

By the end of this activity you will be able to:

- Determine the uniform velocity of a moving object.
- Plot the graphical relation between distance and velocity

Skills to be acquired

Observation Measurement Draw a conclusion Team work Using technical instruments

Tools and Materials

A car toy operates via batteries - A metric ruler A digital camera or cell phone camera – A computer

First- Practical Experiments

(1) Determination of the velocity of a moving object:

Experiment overview:

When an electric car toy moves on a smooth surface, it moves at a uniform velocity in a straight line. If a metric ruler is placed aside of the car track and we photographed the car using a digital camera, we can explore the relation between distance and time when displaying this video. Usually during display, a video provides a counter for seconds.

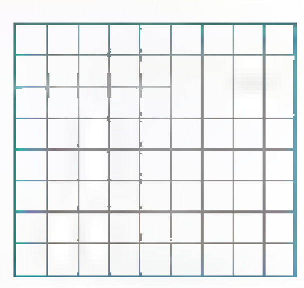
Procedure:

1. Fix a metric ruler aside the path that the car would pass by.
2. Choose one of your team to act as a cameraman.
3. Place the car at the start line. Allow it to move in a straight line parallel to the ruler.
4. Record the car motion using the camera.
5. Adjust the computer to display the record a shot after another by clicking pause every 5 seconds.
6. Determine the car position at each instant by reading the metric ruler on video display. Tabulate your data.

Results: Record the obtained results in the following table:

Time t (s)	Distance d (m)
0	....
5	....
10	....
15	....
20	....

Results Analysis: Through the obtained results in the table, plot the graphical relation between distance (d) on the vertical axis and time (t) on the horizontal axis.



Conclusion: It is known that when an object moves at uniform velocity,

$$d = vt$$

This means that the slope of line =

$$v = \frac{\Delta d}{\Delta t}$$

Finding the slope of line from the graph, we find that velocity = ...

Enrichment Activities: Design experiments to find out answers for the following questions:

- What is the effect of the surface harshness on the car motion?
- How can you measure the velocity of a bicycle rider?

Second – Evaluation Activities

1. Prepare a photo album, either software or hardware about motion in different sports and amusement games. Classify each motion into either periodic or translational.

2. Discuss with your colleagues traffic problems in Egypt. Try to suggest as many solutions as possible for these problems.
3. Write down a research about the development of transportation through mankind history. Estimate the maximum speed by which each of them moved. Record your data in a table.

Third – Questions and Exercises

1. Calculate the average velocity in km/h for an athlete who covered a distance of 400 m in 30 minutes. Then, find the distance covered in 45 minute from start if the average velocity was kept unchanged.

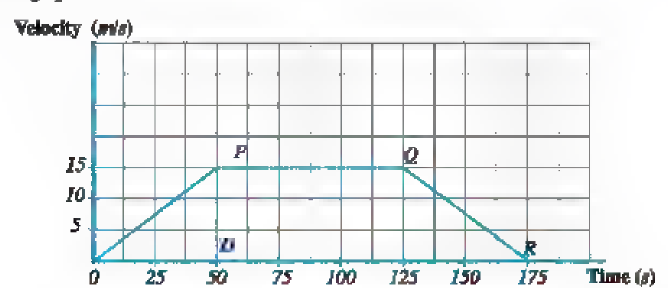
2. A student carried out an experiment to study the motion of a cart using a ticker- timer where the position of the cart is determined every second on a ticker- tape as shown in figure:

a. Describe the motion of the cart.

b. Find the average velocity if (A) is at 190 m from (B).

c. Find the acceleration of the cart.

3. The graph below represents a journey of a car. Study the diagram and answer the following questions:



a. What is the greatest velocity of the car motion?

b. Describe the car motion in section PQ.

c. Describe the car motion in section QR.

d. Which point P, Q or R represents the first instant of applying the brakes?

(c) Calculate the total distance traveled by the car in this journey.

(5) Represent the data recorded in the table below graphically. Then, find from the graph both acceleration and displacement after 12 s.

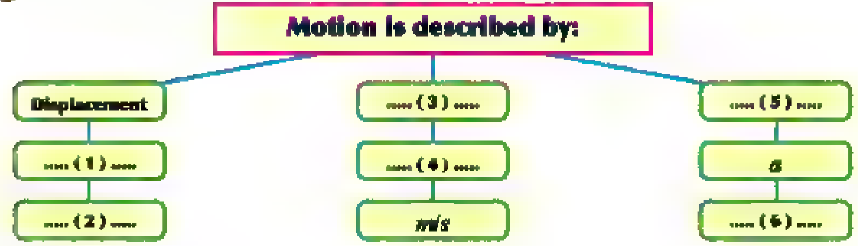
Time (*s*)	0	6	9	12
Velocity (*m/s*)	8.1	36.9	51.3	65.7

(6) A ball rolled on a surface when it had been pushed, then it slowed down and stopped. Did the ball velocity and acceleration have the same sign? Why?

(7) If the acceleration of an object equals zero, does this mean that its velocity must equal zero? Give an example.

(8) If the velocity of an object at a given instant equals zero, is it necessary that its acceleration equals zero? Give an example.

(9) Complete what is missing in the following concept map:



(9) Enjoy crosswords:

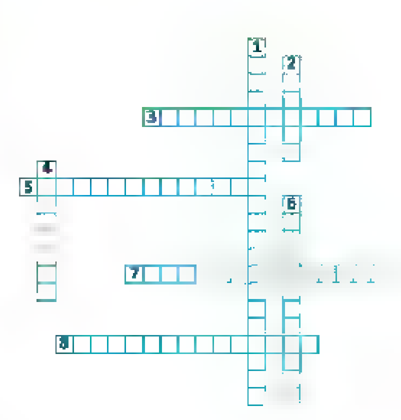
Across:

(3) A type of motion which is characterized by having a starting point and end point

(5) The motion that repeats itself over equal intervals of time

(7) The quotient of total displacement and total time.

(8) The object velocity when it is displaced through equal displacements in equal times.



Down:

(1) The velocity of the object at a given instant.

(2) The change in the object position as the time passes

(4) The displacement of the object in one second.

(6) The change of the object velocity per unit time.

Chapter Two

Motion with Uniform Acceleration

Expected Learning Outcome

By the end of this chapter you will be able to:

- Deduce the equations of motion at uniform acceleration.
- Identify the motion of objects under free fall.
- Conclude the motion in two dimensions such as projectile motion.
- Design an experiment to determine the free fall acceleration.

Physical Terminology

- *Uniform acceleration.*
- *Equations of motion.*
- *Free fall.*
- *Projectile motion.*

Learning Resources

- Interacting demonstration: falling of two objects of different weights from Tower of Pisa.
https://sites.google.com/site/physicsflash/home/air-drag

You have studied in the previous chapter that acceleration is the change in velocity per unit time. This acceleration may be uniform (constant) or varying.

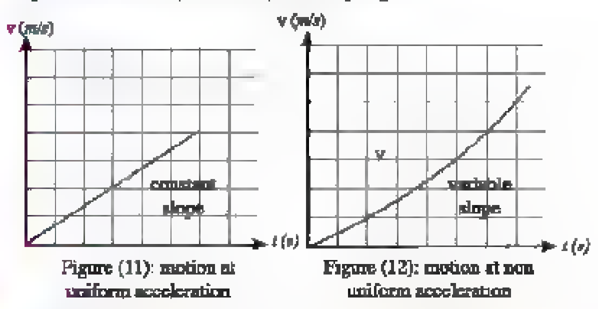


Figure (11): motion at uniform acceleration

Figure (12): motion at non uniform acceleration

Motion of an object at uniform acceleration has a special importance since it represents the motion of a number of objects in our experience. Examples may include those objects falling near the Earth's surface and projectiles.

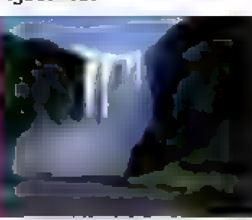


Figure (13): falling of water from the top of a waterfall is at uniform acceleration

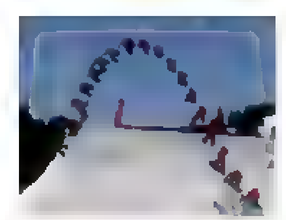


Figure (14): skating in air is at uniform acceleration

Assuming that an object moved in a straight line at uniform acceleration (a), and started motion from rest at initial velocity (v_i) It reached a final velocity (v_f) after an interval (t) during which it was displaced through a displacement (d). We can describe such motion using certain equations called equations of motion as follows:

1- Equation of (Velocity - Time)

You know that acceleration (a) is given by the relation

$$a = \frac{v_f - v_i}{t}$$

The change of velocity $(v_f - v_i)$ can be obtained by multiplying both sides by (t)

$$v_f - v_i = at$$

$$v_f = v_i + at \qquad (1)$$

This is the first equation of motion that means:

Final velocity = initial velocity (v_i) + change of velocity (at)

Thinking Corner

- Compare the acceleration of motion of the fastest animal on Earth and that of one of the fastest cars using the previous equation.

Figure (15): Cheetah can change its speed from zero to 110 km/s in 3 seconds

Figure (16): Bugatti Veyron car changes its speed from zero to 100 km/s in 2.4 seconds

2- Equation of (Displacement - time)

The average velocity of a moving object can be given by the relation: $(\overline{v})$

$$\overline{v} = \frac{d}{t}$$

Since the object moves at uniform acceleration, the average velocity can be given by the relation:

$$\overline{v} = \frac{v_f + v_i}{2}$$

From the two forms

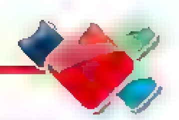
$$\frac{d}{t} = \frac{v_f + v_i}{2}$$

Substituting (v_f) from the first equation of motion:

$$\therefore \frac{d}{t} = \frac{(v_i + at) + v_i}{2} = \frac{2v_i + at}{2} = v_i + \frac{1}{2}at$$

Multiplying both sides by (t), we obtain:

$$\therefore d = v_i t + \frac{1}{2}at^2 \qquad (2)$$



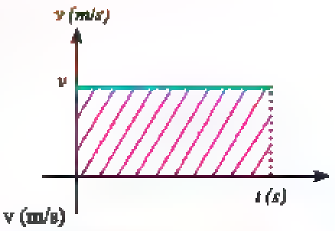
Pay Attention

- When the object moves in a straight line in one direction, its displacement (d) equals the distance it covers (s).
- When the object moves in a straight line but changes direction, such as the object that is projected vertically upwards then falls back to surface, its displacement (d) does not equal the distance it covers (s).

Deriving the second equation of motion graphically:

Since displacement = velocity x time, this corresponds the numeral value of the product length x width in the (velocity – time) graph, or in other words the area below the curve.

Accordingly, we can deduce the second equation of motion and find the displacement of the object by getting the area below the curve in (velocity – time) graph i.e. the area of both the rectangle and the triangle.



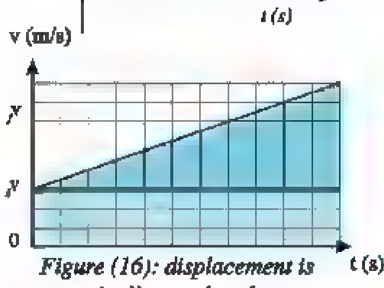


Figure (16): displacement is numerically equal to the area below the curve.

The area of rectangle $= v_i\, t$

The area of the triangle $= \frac{1}{2}(v_f - v_i)\, t$

Since the change in velocity $(v_f - v_i)$ equals (at)

The area of the triangle becomes: $\frac{1}{2}\, at^2$

The object displacement (d) = sum of the areas of the rectangle and the triangle

$$d = v_i t + \frac{1}{2} at^2$$

Activating Creativity

- Innovate other ways to deduce the second equation of motion graphically, for example by considering the area below the curve as a trapezium or two triangles, etc.

3- Equation of (Displacement - Velocity)

Sometimes time of motion is unknown. Because of this we need to deduce an equation independent on time as follows:

Displacement of object can be determined by the relation: $d = \overline{v}\, t$

Substituting ($\overline{v}$) and (t) using the following formulae:

$$\overline{v} = \frac{v_f + v_i}{2} \qquad t = \frac{v_f - v_i}{a}$$

Thus, displacement can be found as follows:

$$d = \overline{v}\, t = \frac{v_f + v_i}{2} \times \frac{v_f - v_i}{a} = \frac{v_f^2 - v_i^2}{2a}$$

The third equation of motion can be obtained:

$$\therefore 2ad = v_f^2 - v_i^2 \quad (3)$$

Three equations of motion are obtained right now that can be applied to the motion of an object at uniform acceleration. Except for time, all the included quantities are vectors. So, First of all a positive direction should be agreed at. For instance, if the direction to right is considered positive, displacement, velocity and acceleration are positive if their directions are to right and negative if their directions are to left. The table below summarizes some cases based on equations of motion

General formula	Motion starts from rest $v_i = 0$	Stopping at the end of motion $v_f = 0$	Motion at uniform velocity $a = 0$
$v_f = v_i + at$	$v_f = at$	$v_i = -at$	$v_f = v_i$
$d = v_i t + \frac{1}{2}at^2$	$d = \frac{1}{2}at^2$	$d = -\frac{1}{2}at^2$	$d = v_i t$
$2ad = v_f^2 - v_i^2$	$2ad = v_f^2$	$2ad = -v_i^2$	$0 = v_f^2 - v_i^2$

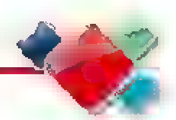
Overcoming Learning Difficulties

You may find difficulty in converting the word problems into a mathematical form. The following guidelines may help:

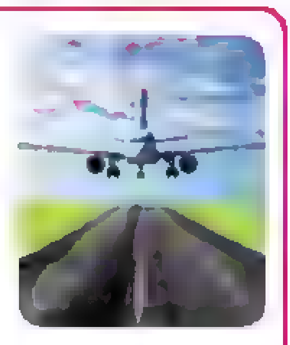
- Its speed increases means: acceleration is positive (if velocity is positive)
- Its speed decreases means: acceleration is negative (if velocity is positive)
- When ? Means find the time (t)
- Where? Means find the displacement.(d)

Time management:

- Estimate the time interval expected to finish a particular activity.
- Make balance between studying, doing assignments, and homework at one hand, social events, hobbies and fun at the other hand. Evaluate the importance of various duties and tasks and arrange priorities.



Solved Examples



An areoplane lands on the runway at velocity 162 km/h and decelerates uniformly at ($0.5 m/s^2$) Find the time it takes till stops.

Solution:

$v_i = 162 \times \frac{5}{18} = 45$ m/s $\qquad v_f = 0$

$a = -0.5$ m/s^2 $\qquad v_f = v_i + a\,t$

$0 = 45 + (-0.5)\,t$ $\qquad -45 = (-0.5)\,t$

$t = 90$ s

a person drove a car at uniform velocity (*30 m/s*). Suddenly, he saw a child crossing the street and he applied the brakes to decelerate the car uniformly at (*9 m/s^2*). If the person reaction time to use the brakes is (*0.5s*), find the displacement of the car till it stopped.

start responding braking end

0 +x

start v end

a

Solution:

Displacement of the car during reaction time (uniform velocity):

$d_1 = v \cdot t = (30) \times (0.5) = 15m$

Displacement of the car when applying the brakes (uniform acceleration):

Refering to the table in page: (*38*)

$2\,ad_2 = -v_i^2$

Since, v_f (of reaction time) = v_i (when braking)

$\therefore 2\,ad_2 = -v_f^2$ (of reaction)

$\therefore d_2 = \frac{-v_f^2}{2a} = \frac{-(30)^2}{2 \times 9} = 50m$

The total displacement

$d = d_1 + d_2 = 15 + 50 = 65\ m$

Note that the total displacement of the car is the same as the total distance covered by the car if the car keeps moving in a straight line.

- To save souls, avoid the dangers of skipping prescribed speeds, and traffic instructions should be followed. One of these rules is leaving an appropriate distance between vehicles in order to allow the driver to stop safely in case of emergency. Obviously, more spacing is required as the speed of cars get higher, or the road is wet or has oil stains. Also, trucks should leave larger spacing than small cars do.

Typical Stop Spacing

48 km/h — 14 m — 23 m = 6 times the car lenght

64 km/h — 24 m — 36 m = 9 times the car lengnt

80 km/h — 38 m — 53 m = 13 times the car lenght

91 km/h — 55 m — 73 m = 18 times the car lenght

Distance during reaction time

Distance during braking

Applications of motion at uniform acceleration:

Free fall:

If we drop a book and a sheet of paper at the same instant from the same height, which of them reach the ground first? But, when the sheet of paper is placed adjacent to the book topside and allowed to fall, what would you observe? Explain your observation.

When an object falls to ground, its motion is affected by the air resistance due to collisions between the object and air molecules. The impact of this resistance is greater on the velocity of falling light objects than that of heavier objects.

Note that no air resistance affected the sheet of paper when it was placed adjacent to the topside of the book during falling.

To simplify this issue, we are going to study the fall of objects under the effect of their weights, only neglecting the effect of air resistance. This motion is called free fall. It is worthy to mention that at the absence of air resistance, all objects fall to the ground at the same acceleration.

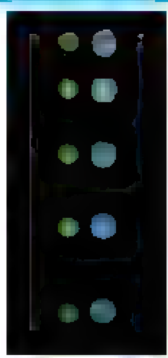


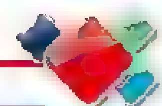
Figure (18): would two objects reach the ground at the same instant in a vacuum?

Distinguished Scientists

- Galileo proved that falling objects of different masses reach the ground at the same time, when air resistance is neglected. By dropping two objects of different masses down Tower of Pisa. This experiment put an end for Aristotle thoughts that implied that heavier objects would reach the ground first.

Figure (19): Galileo's Experiment of free fall

The opposite link shows what happens when 2 objects are dropped on the moon



Free Fall Acceleration (g):

It is the uniform acceleration of objects that fall freely. This acceleration equals ($9.8\ m/s^2$) and means that the object velocity when falling freely increases by ($9.8\ m/s$) every second.

This acceleration (g) varies from one position to another depending on its distance from the Earth's centre. For simplicity, it can be considered ($10\ m/s^2$)

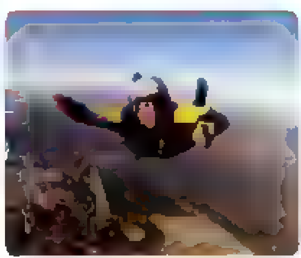


Figure (20) Does this person fall at acceleration $9.8\ m/s^2$?

Solved Examples

Study the table then answer the questions below:

Time (*s*)	Displacement (*m*)	Velocity (*m/s*)
0	*0*	*0*
0.5	*1.25*	*5*
1	*5*	*10*
1.5	*11.25*	*15*
2	*20*	*20*

1. Use equations of motion to calculate displacement and velocity after 3 s.
2. What do you conclude from the spacing increase between the object positions with time?
3. using the data recorded, plot the graphical relationships (displacement - time) and (velocity - time)

Solved Example

A box fell from a helicopter that was staying still at 78.4 m high above sea level. Find the velocity by which the box hit water giving that acceleration due to gravity $9.8\ m/s^2$ neglecting the air resistance. Also, Find the time it took till splash.

Solution:

$v_i = 0$, $g = 9.8\ m/s^2$, $d = 78.4\ m$

$2gd = v_f^2 - v_i^2$ $\qquad 2 \times 9.8 \times 78.4 = v_f^2$

$v_f = 39.2\ m/s$

$t = \frac{v_f - v_i}{d} = \frac{v_f}{d} = \frac{39.2}{9.8}$ $\qquad t = 4\ s$

2 A stone fell from the roof of a building. If the stone passed by a person standing in a balcony 5m high above the ground 4 s later (consider $g = 10\ m/s^2$), find:

A The building height

B The stone velocity when passed by the person.

Solution:

$$d = v_i t + \frac{1}{2} g t^2$$

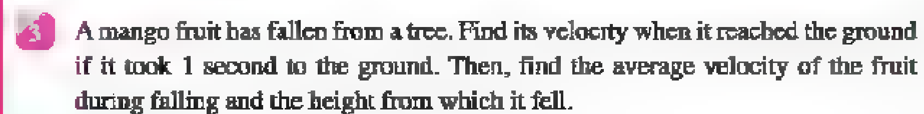
$$d = 0 + (\frac{1}{2} \times 10 \times 16) = 80\ m$$

A The building height: $h = 80 + 5 = 85\ m$

B The stone velocity when passed by the person:

$$v_f = v_i + g\,t$$

$$v_f = 0 + (10 \times 4) = 40\ m/s$$



3 A mango fruit has fallen from a tree. Find its velocity when it reached the ground if it took 1 second to the ground. Then, find the average velocity of the fruit during falling and the height from which it fell.

Solution:

Given data: $v_i = 0 \quad g = 10\ m/s^2 \quad t = 1\ s$

Velocity of reaching the ground: $v_f = v_i + gt = gt$

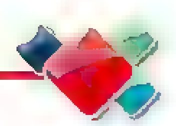
$$v_f = 10 \times 1 = 10\ m/s$$

The average velocity of the fruit during falling: $\overline{v} = \frac{v_f + v_i}{2}$

$$\overline{v} = \frac{10 + 0}{2} = 5\ m/s$$

The height from which the fruit fell: $d = v_i t + \frac{1}{2} g t^2 = \frac{1}{2} g t^2$

$$\therefore d = (\frac{1}{2})(10)(1)^2 = 5\ m$$



Solved Example

In an experiment to determine the acceleration due to gravity using falling water drops, the distance between the tap and the plate base is (*1m*). If the time taken by (*100*) drops is (*45 s*), find the acceleration due to gravity.

Solution:

Given data: $d = 1m$, $v_i = 0$, $t = ?$, $a = ?$

Time taken by one drop to fall (t) $= \dfrac{\text{Total time}}{\text{Number of drops}} = \dfrac{45}{100} = 0.45\ s$

Substituting in the second equation of motion:

$$d = \frac{1}{2} g t^2$$

$$g = \frac{2d}{t^2} = \frac{2 \times 1}{0.45 \times 0.45} = 9.88\ m/s^2$$

Projectiles

(a) Vertical projectiles:

- When an object is projected vertically upwards, it leaves the hand at initial velocity (v_i).
- The object moves at uniform acceleration ($-10\ m/s^2$). The negative sign indicates that the direction of acceleration is opposite to that of velocity.
- Velocity decreases gradually as the object gets higher till its velocity reaches zero at maximum height.
- Direction of velocity changes when the object returns back to the ground under the effect of the Earth's gravity that makes the object accelerate.
- Velocity of the object when projected up = - its velocity at the same point on falling. The negative sign indicates that the two velocities are in opposite directions.
- Time of rise = time of fall.

Solved Example

Time, displacement, and velocity of an object projected vertically upwards at initial velocity (*20 m/s*) are recorded in the table below:

Time (*s*)	*0*	*0.5*	*1*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*
Displacement (*m*)	*0*	*8.75*	*15*	*18.75*	*20*	*18.75*	*15*	*8.75*	*0*
Velocity (*m/s*)	*20*	*15*	*10*	*5*	*0*	*-5*	*-10*	*-15*	*-20*

This motion can be represented by the following diagrams:

Figure (21): projectile path

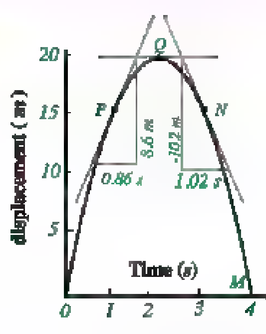


Figure (22): change of displacement with time

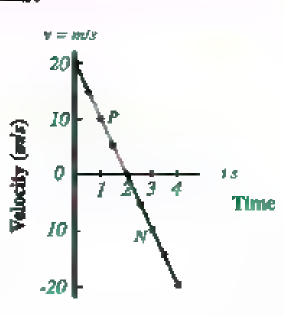


Figure (23): change of velocity with time

1. Determine the object velocity at the points *P*, *Q* and N in the (displacement – time) and (velocity – time) graphs.
2. What is the slope of the line in (velocity – time) graph? What does it represent? Why has it got a negative sign?

Solution:

1. Finding velocity by the slope of tangent at points Q , P and N in (displacement - time) graph

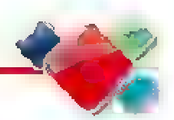
$$v_Q = 0 \qquad v_P = \frac{8.6}{0.86} = 10 \text{ m/s} \qquad v_N = \frac{-10.2}{1.02} = -10 \text{ m/s}$$

These values are the same as those obtaind in (velocity - time) graph.

2. Acceleration (a) is the slope of line in (velocity - time) graph:

$$a = \frac{\Delta v}{\Delta t} = \frac{-20}{2} = -10 \text{ m/s}^2$$

The negative sign indicates that the object velocity is decreasing as it goes further from the ground.



(b) Projectiles when projected at an angle (Motion in two dimensions):

You have studied the motion of objects at uniform acceleration in a straight line either in a horizontal, inclined or vertical plane. At the moment, we are going to study objects motion when projected at an angle to the horizontal under the effect of gravity

Figure (24): why does water move in parabola?

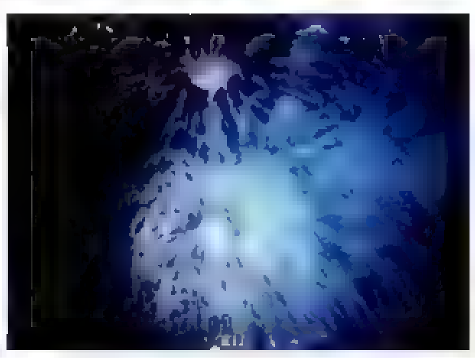


Figure (25): why do sparks move in parabola?

Studying the projectile motion such as that of a ball or a cannon shell shows that it takes a curved path (figure 26). It starts motion at initial velocity (v_i) at angle (θ) to the horizontal. We can resolve velocity into two dimensions; horizontal (x) and vertical (y) as shown:

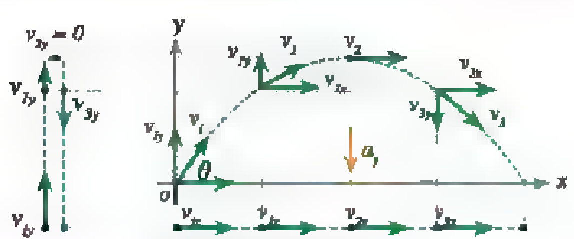


Figure (26): Projectile Motion

The horizontal dimension (x): the ball velocity is uniform (v_{ix}) neglecting any friction. This velocity can be found by the relation:

$$v_{ix} = v_i \cos \theta$$

Substituting in the three equations of motion by the value of (v_{ix}), considering ($a_x = 0$):

The vertical dimension (y): the ball moves at the acceleration due to gravity. Consequently, velocity varies. We can find the initial velocity in the vertical dimension (v_{iy}) by the relation:

$$v_{iy} = v_i \sin \theta$$

Substituting in the three equations of motion by the value of (v_{iy}) considering ($a_y = g = -10\ m/s^2$)

The velocity of the projectile at any instant is given by Pythagoras' relation:

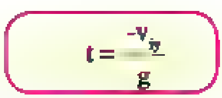
$$v_f = \sqrt{v_{fx}^2 + v_{fy}^2}$$

Finding the time of reaching maximum height (t):

Substituting in the first equation of motion by ($v_{fy} = 0$), we obtain:

$$0 = v_{iy} + gt$$

i.e. :



$$t = \frac{-v_{iy}}{g}$$

Time taken till returning back to the plane of projection (flight time):

$$T = 2t = \frac{-2v_{iy}}{g}$$

Finding the maximum height reached by the projectile (h):

Substituting in the third equation of motion by ($v_{fy} = 0$), we obtain:

$$2g\,h = -v_{iy}^2$$

i.e

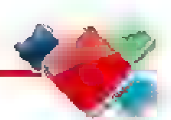
$$h = \frac{-v_{iy}^2}{2\,g}$$

Finding the range (the horizontal distance reached by the projectile) (R):

Note that: T = time of the horizontal range = flight time

Substituting (a_x = o) and (d = R) in the second equation of motion, we find:

$$R = v_{ix}T = 2v_{ix}\,t$$



Solved Example

A motocycle is launched at *15 m/s* in a direction at an angle *30°* to the horizontal.

(A) What is maximum height reached by the motorcycle?

(B) Find the time of its flight.

(C) What is the horizontal range reached by the motorcycle?

Solution:

First, find the value of (v_{ix}) and (v_{iy}):

$$v_{ix} = v_i \cos 30 = 15 \times 0.866 = 13 \text{ m/s}$$

$$v_{iy} = v_i \sin 30 = 15 \times 0.5 = 7.5 \text{ m/s}$$

Finding maximum height (h):

$$h = \frac{-v^2_{iy}}{2\,g} = \frac{-(7.5)^2}{2\times(-10)} = 2.8 \text{ m}$$

Finding the time of flight (T):

$$T = 2t = \frac{-2 \times v_{iy}}{g} = \frac{-2\times 7.5}{(-10)} = 1.5 \text{ s}$$

Finding the horizontal range (R):

$$R = v_{ix}\,T = 13 \times 1.5 = 21.5 \text{ m}$$

Do You Know?

- The projectile reaches maximum horizontal range when it projected at an angle *45°*. And the horizontal range is the same when the projectile is projected at Complementary Angles (Angles having a sum equal to *90°*)

Activities and Exercises

Chapter Two

Motion at a Uniform Acceleration

Safety Rules

By the end of this activity you will be able to:

- Determine the acceleration due to gravity using simple tools.

Skills to be acquired

- Observation - Measurement - Accurate measurement - Draw a conclusion - Team work

A metric ruler – A stopwatch - A metal dish - A vessel provided with a tap.

First- Practical Experiments

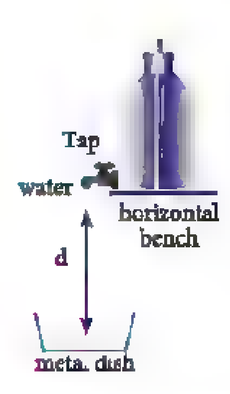
(1) Determination of the acceleration due to gravity:

Experiment overview:

If the time (t) taken by a water drop to fall through a displacement (d) is determined, the free fall acceleration can be found by the relation:

$$d = \frac{1}{2} gt^2$$

Procedure:



1. Prepare the apparatus to function by adjusting the distance between the tap and the dish surface to be exactly 1 m.
2. Control the tap carefully to allow a water drop to fall just at the instant of hearing the splash of the previous drop hitting the dish base. Accordingly, the time taken by the drop to fall becomes equal to the time between dripping two successive drops from the tap.
3. Use a stopwatch to record the time taken by 50

successive drops to drip. Then, find the time between dripping of two successive drops (t).

Time taken by one drop to fall = $\frac{\text{Total time}}{\text{Number of drops}}$

4. Repeat the previous procedure several times and find the average time taken by one drop to fall

Results:

Trial	Time of 50 successive drops	Time of one drop (t)
1	....	....
2	....	....
3	....	....
4	....	....

Average time taken by one drop to fall = ...

Results Analysis:

Find the free fall acceleration using the relation:

$$d = \frac{1}{2} gt^2$$

Conclusion:

Acceleration due to gravity = ...

Enrichment Activities

Design experiments to find out answers for the following questions:

- Would objects of different masses fall at the same free fall acceleration?
- How can you determine the free fall acceleration using a simple pendulum?

Second – Evaluation Activities

1. **Ibn-Malka El-Baghdady is a physician and a philosopher who became famous in the sixth century after Hijrah and considered "Unique of his Time". He was born and grown up in Basra, then traveled to Baghdad to work for the two Abbasid Caliphs; Al-Moktada and Al-Mostanser. He got a great stature that he was known in his time as the "Iraqis philosopher". Write down a research about the contributions of Ibn-Malka in physics.**

2 **Cooperate with your colleagues to design models for ejectors using materials from your environment such as: rubber bands, wood sticks, pencils, etc. Use these models to investigate the factors that affect the projectile motion. Apply your factors to control the projectile trajectory to hit a target at a particular distance.**

- How does the angle of projection affect on its trajectory?
- How does the tension force in the string affect on its trajectory?
- What is the effect of the projectile features on its trajectory?
- To what extent your results may change if carried out in the open?

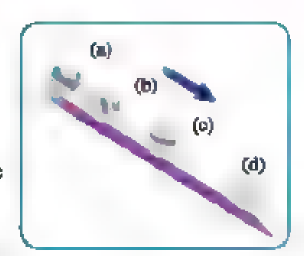
Safety Rules

- Do not direct projectiles towards your colleagues
- Never hurt your colleagues by rubber bands.

3 **Studies have indicated that accident victims on roads and railways in Egypt estimated by 6500 persons in one year. On the other hand, in two years about 67 thousands have been injured or lost parts of their bodies. Discuss the problem of road accidents suggesting some solutions.**

Third – Questions and Exercises

1 This figure illustrates a ball rolling down a smooth plane at a uniform acceleration. Points of (A, B, C, and D) indicate the ball position every 0.5 s. Based on figure, answer the following:



a. How can you detect that the ball is speeding up?

....

b. Why does velocity increase?

....

c. Calculate the ball acceleration if the distance between (A) and (D) = 2m.

....

2 A person at the roof of a high building has projected a ball at velocity of 50 m/s. Given that the acceleration due to gravity is 10 m/s^2, find the velocity and displacement of the ball after 4 s in the following cases:

a. The ball has been projected vertically upwards.

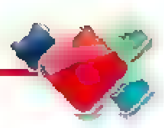
....

b. The ball has been projected vertically downwards.

....

c. The ball has been projected upwards at an angle 30° to the horizontal.

....



d) The ball has been projected horizontally.

3 Choose the correct answer for each phrase of the following:

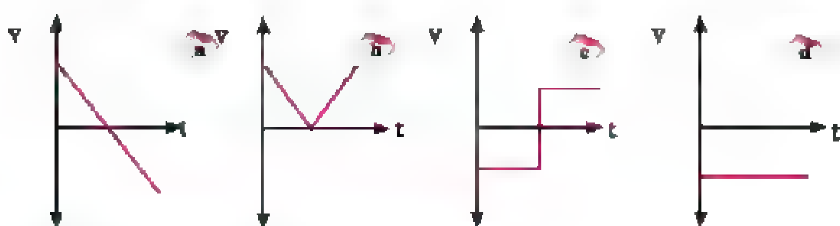
1. Dimensions of acceleration are ....
   - a) LT^{-1}
   - b) LT^{-2}
   - c) $L^{-1} T^{-2}$
   - d) $L^{-2} T^{-2}$

2. When the change in velocity of an object is zero, ...
   - a) its acceleration is positive.
   - b) its acceleration is negative.
   - c) its acceleration is zero.
   - d) the object is at rest.

3. If both directions of velocity and acceleration are negative, ...
   - a) velocity of the object increases.
   - b) velocity of the object decreases.
   - c) velocity of the object is constant.
   - d) the object stops motion.

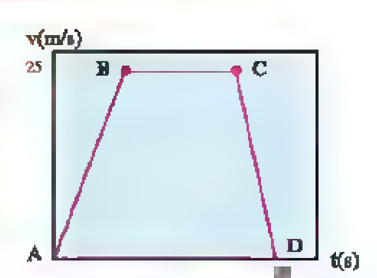
4. Two bodies of different materials having the same volume fall freely together from the same height. Which statement describes correctly their arrival to the ground?
   - a) The heavier body reaches first.
   - b) The lighter body reaches first.
   - c) The heavier body accelerates more
   - d) They reach the ground at the same time.

5. The graph that best describes an object projected vertically upwards and returned back to the point of projection, having the direction of initial velocity positive, is ...



4 What is meant by each of the following:

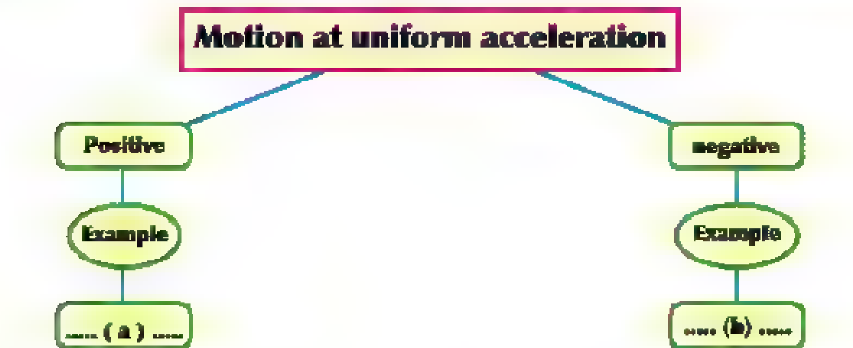
- a) Displacement of a table is 3m ?
- b) Velocity of a bicycle is 5m/s ?
- c) Free fall acceleration is 9.8 m/s^2 ?



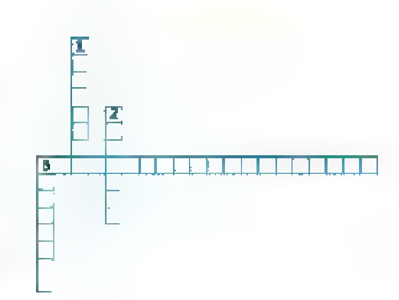
(5) The velocity of a car moving in a straight line was recorded during 30 seconds and then represented graphically as shown. Work in pairs to analyze the diagram and extract the information required to complete the table below:

Stages of car motion	Stage AB	Stage BC	Stage CD
Initial velocity (v_i)			
Final velocity (v_f)			
Change of car velocity (Δv)			
Time of stage (t)			
Acceleration (a)			
Description of motion during the stage			

(6) Complete what is missing in the following concept map:



(7) Enjoy crosswords:



Across

(3) The uniform acceleration by which objects move during free fall.

Down

(1) Numerically equal to the area below the curve in velocity-time graph.

(2) A type of acceleration when the rate of change of velocity is constant.

(3) The fall of objects under the effect of their weight only

Chapter Three

Force and Motion

Expected Learning Outcome

By the end of this chapter you will be able to:

- Apply the relation between force, mass, and acceleration.
- Explain the action – reaction coupling.

Physical Terminology

- *Force*
- *Action*
- *Reaction*
- *Mass*
- *Weight*

e- Learning Resources

- Educational song: Newton's laws of motion.
  http://www.youtube.com/watch?v=oDLaSWQjE2E
- Educational video: Explanation of Newton's laws of motion.
  http://www.youtube.com/watch?v=CrUBThAFaT0
- Interesting experiments: Newton's first law of motion and inertia.
  http://www.youtube.com/watch?v=Udv7RvYtAK0

Previously we have described motion by studying the concepts of velocity and acceleration without getting into the reasons beyond.

In this link below we are going to discuss the existence of acceleration due to the impact of a force. This leads us to Newton's laws of motion that are considered as basic laws in physics.

Newton's First law

May you have returned home one day after a long absence and looked around and wondered: "alright, everything is in place, isn't it?" Have you ever thought that you have just stated one of the most important laws in nature!

Moreover, it is known that a rolling object on the floor would move for a certain distance, slowing down, then stops. Ancient people thought that the normal nature of an object was being static; meaning that every motion devolves to rest. But, experiments show that the rolling object experiences forces of friction that slow it down till stop. If these forces do not exist, the object would keep moving and would not stop. This principle is known as Newton's First Law of motion.

Newton's First Law of motion: "A static object keeps its state of rest, and a moving object keeps its state of motion at uniform velocity in a straight line unless acted upon by a resultant force." The mathematical formula that expresses the law: $\sum F = 0$

The term Δ F is the resultant force that may equal zero when the forces acting on an object may cancel the effect of each other.

A static object keeps its state of rest

unless acted upon by a resultant force

A moving object keeps its state of motion at uniform velocity in a straight line

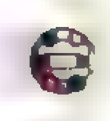

unless acted upon by a resultant force

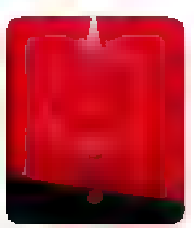
Figure (28). Newton's First Law of Motion

Applying Newton's First Law, we can draw a conclusion that when the resultant force = 0, acceleration = 0, and no change happens in object velocity either being static or dynamic. Also, a resultant force is needed to move a static object or to stop a moving one. No need for a resultant force to move objects at uniform velocity in a straight line.

Newton's First Law is related to the concept of inertia. Accordingly, it is called "Law of Inertia"

Inertia: the tendency of an object to keep either its state of rest or state of motion at its original velocity uniformly in a straight line. This means that objects resist changing its static or dynamic state.

Based on the concept of inertia explain the following daily observations:


Fall of crayon into the bottle when the ring is removed rapidly

Motorcycle rider flies off the motorcycle when it hits an obstacle.

Seat belt should be fastened on driving.

Figure (29): daily observations based on inertia

Technological Applications

When being away from the Earth's gravity, a space rocket does not need to consume fuel to keep moving because inertia keeps it moving at uniform velocity in a straight line.

It is noticeable that the possibility of stopping objects that move under the influence of inertia depends on the mass of these objects and their velocity so that

- It is difficult to stop a speeding truck while it is easy to stop a small motorcycle assuming that they are moving at the same velocity.
- It is difficult to stop a car moving at high speed while it is easier when moving at low speed.

The two previous observations indicate that velocity and mass join together to from an important physical quantity known as momentum

Momentum = mass x velocity

$P = mv$

Since velocity is a vector, then momentum is also a vector, and its direction is the direction of velocity, and the momentum unit is (kg m/s)

Newton's second law

We have learnt that when no resultant force affects the object, it does not move at acceleration. Consequently, when a resultant force acts on the object ($\Sigma F \neq 0$), it moves at acceleration. Accordingly, its velocity changes and it acquires acceleration ($a \neq 0$).

Through his second law, Newton defined the factors affecting such acceleration.

Newton's Second Law of Motion

"The resultant force affecting an object equal to the rate of change of its momentum"

And from Newton's Second Law

$$F = \frac{\Delta mv}{\Delta t} = \frac{mv_2 - mv_1}{\Delta t} \qquad F = m\frac{v_2 - v_1}{\Delta t} = m\frac{\Delta v}{\Delta t}$$

$$F = ma \quad \Rightarrow a = \frac{F}{m}$$

From the previous relation we can conclude that acceleration is directly proportional to the resultant force on the object and inversely proportional to its mass

Less force, less acceleration. | greater force, greater acceleration.

Figure (30): increase of acceleration with force.

Less mass, more acceleration | greater mass, less acceleration.

Figure (31): decrease of acceleration with mass

Newton's Second Law of motion: "when a resultant force affects an object, the object acquires an acceleration which is directly proportional to the resultant force and inversely proportional to the object mass." The mathematical formula that expresses the law: $a = \frac{\Sigma F}{m}$ or $\Sigma F = ma$

Representing the relationship between acceleration and the acting force graphically, we notice that the acceleration of motion increases as the force increases. Also, the less mass object (say, *100 kg*) moves at a greater acceleration than a heavier one (*200 kg*) does, when affected by the same force.

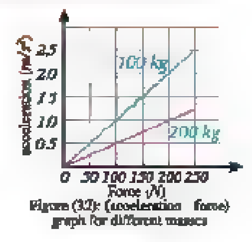


Figure (32): (acceleration - force) graph for different masses

Through Newton's Second Law, we can state a definition for the unit of force, "The Newton"

The Newton: is the force that when acts on an object of mass 1 kg accelerates it at 1 m/s^2.

i.e. 1 Newton = 1 kg. m/s^2

[illegible]

- A force of 1N acts on a wooden cube and accelerates it at certain acceleration (a). When this force acts on another cube and accelerates it at acceleration (3a). What do you conclude about the masses of the two cubes?

Mass and Weight

Through Newton's Second Law, we can infer that moving or stopping a heavy body as a plane is much difficult than a lighter body as a bicycle. In other words, the plane resists the change in its Kinematic state more than that done by the bicycle. Therefore, mass of an object is defined by its resistance to change its Kinematic state.

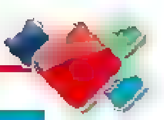
Figure (33): the plane mass is its resistance to change its Kinematic state

Thinking Corner

- When a truck collides with a small car, which of them is affected by a greater force?

Also we can infer that acquiring acceleration implies the existence of force acting on the object. In case of moving at free fall acceleration, the object is under the effect of the gravitational force of Earth.

Therefore, weight of an object is defined as the force of gravity acting on the body. Its direction is towards the Earth's centre and determined by the relation: $w = mg$.



Newton's third law

Figure (34): what happens when air in an inflated balloon is allowed to rush out?

Figure (35): what happens when kicking an opposite wall while sitting on a desk chair?

Figure (36): what happens to the rifle when the bullet goes out?

Newton formulated an explanation for the above mentioned situations through his third law of motion that studies the nature of forces acting on objects. He noticed that forces act in pairs of equal magnitude and opposite directions.

Figure (37): reaction and action have equal magnitude and opposite directions

Newton's Third Law of motion: "when an object acts on another object by a force, the second object reacts with an equal force on the first object in a direction opposite to that of action."

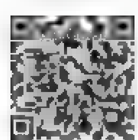
i.e. For every action there is a reaction equal in magnitude and opposite in direction.
The mathematical formula that expresses the law : $F_1 = - F_2$

Figure (37): the two spring balances read the same

Third law of motion implies that:

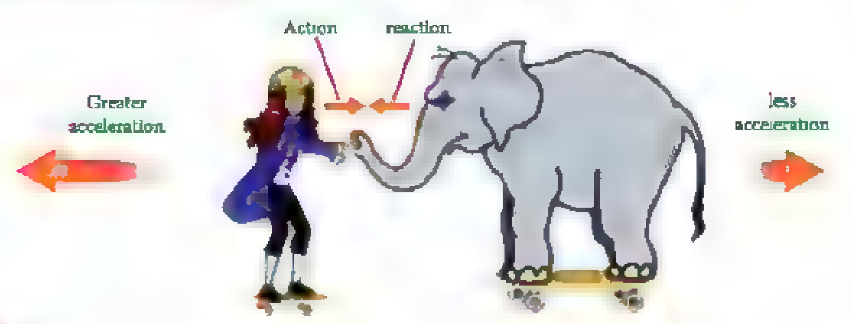
- No single force exists in the universe. Action and reaction are paired; originate and vanish together.
- Action and reaction are of the same type; if the action is a gravitational force, reaction is a gravitational force, as well.
- It is not a must that action and reaction are at equilibrium since they may act on different bodies.

The link below shows Newton's third law of motion and some applications



Solved Example

Study the following figure, then answer the questions below:



1. What is the relation between the force acting on the elephant and that on the man?
2. Why are not action on the elephant and reaction on the man at equilibrium?
3. If the elephant's mass is 6 times heavier than the man's mass, calculate the acceleration by which the elephant moves giving that the man moves at an acceleration $2 m/s^2$. Why is the elephant acceleration negative?

Solution:

1. The force acting on the elephant = the force acting on the man.

$$F_1 = -F_2$$

2. For two forces to be at equilibrium, they must be equal, opposite, having one line of action and act on the same body. All these conditions except the last one may be applied on action and reaction; since the action acts on the elephant and the reaction is on the man. .
3. Finding acceleration of elephant's motion:

$$F_1 = -F_2$$

$$m_1 a_1 = m_2 a_2$$

$$\frac{-a_1}{a_2} = \frac{m_2}{m_1}$$

$$\text{since} \quad m_2 = 6m_1$$

$$\frac{2}{a_2} = 6$$

$$a_2 = \frac{1}{3} \, m/s^2$$

The negative sign indicates that the elephant motion is opposite to the man motion.

Activities and Exercises

Chapter Three

Force and Motion

Safety Rules

Expected Learning Outcomes

By the end of this activity you will be able to:

- Conclude the relation between acceleration of object motion and its mass when affected by a force.

Skills to be acquired

- Observation - Measurement - Accurate measurement - Draw a conclusion - Team work

Tools and Materials

Smooth wooden board – Meter ruler – Thread – Small hook – Weights – Metal wire – Stopwatch

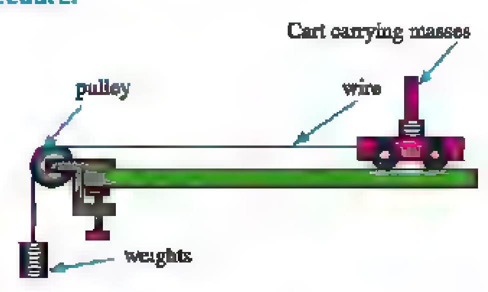
First- Practical Experiments

(1) The relation between acceleration and force:

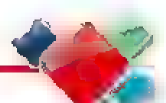
Experiment overview:

When a force acts on an object, it moves at acceleration. To find the relation between acceleration and force, a small cart is pulled using a known force (the force due to the weight of known loads) and its acceleration of motion is determined by the relation: $a = \frac{F}{m} = \frac{w}{m}$ Plotting a graph of acceleration versus force, the relation between them can be concluded.

Procedure:



1. Set up the tools as shown in figure.
2. Add loads gradually to the hook (5 g each time) till the cart starts motion slowly at uniform velocity that means that the weight of these loads has balanced friction.
3. What do you expect when other masses are added?
4. Now, hang a load of 10 g to the hook.
5. Measure the distance moved by the cart (d).



6. Allow the car to move and measure the time (t) taken to cover the distance (d) Repeat this step several times and find the average value.
7. Add another load (10 g) to the hook and re-measure the time (t) taken to cover the distance (d). Add a third load (10 g) and repeat the procedure. Tabulate your results:

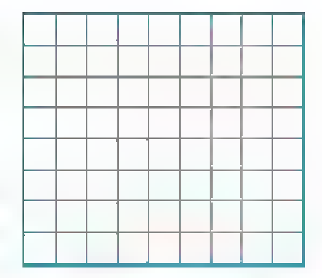
Results:

a. Calculate the moving force acting on the cart each time $F = mg = 10m$.
b. Find the acceleration of the cart motion using the relation: $a = 2d/t^2$
c. Record the results in the table below:

Mass	Force	Time (t)	Square of time (t^2)	Displacement	Acceleration
0.01 kg	*0.1 N*	....	....	....	....
0.02 kg	*0.2 N*	....	....	....	....
0.03 kg	*0.3 N*	....	....	....	....

Results Analysis: Plot a graph for the relation between force on the vertical axis and acceleration on the horizontal axis.

- Find the slope of the line and use it to determine the mass of the cart.



Conclusion:

....

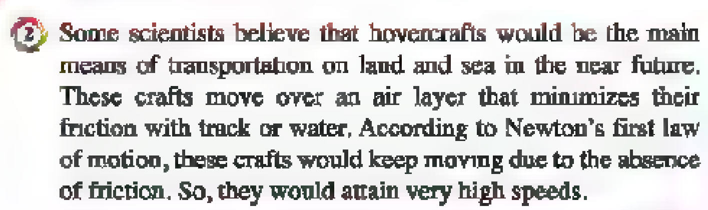
....

....

....

Second – Evaluation Activities

1. Design a model for a rocket propelled by air. Pass a straw about a wire which is suspended between two opposite walls. Stick an inflated balloon to the straw meanwhile its slot is closed between your fingers. Open the balloon slot to allow air to rush out. Where is the balloon motion directed? What is the similarity between the balloon motion and the rocket motion?



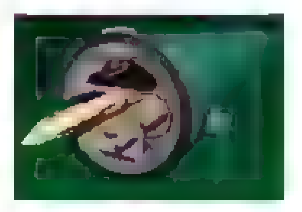
(2) Some scientists believe that hovercrafts would be the main means of transportation on land and sea in the near future. These crafts move over an air layer that minimizes their friction with track or water. According to Newton's first law of motion, these crafts would keep moving due to the absence of friction. So, they would attain very high speeds.

Cooperate with your colleagues to design a model for a hovercraft using materials from your environment such as: bottle lid, a balloon, adhesive material, and a compact disk.

Hovercraft model

(3) China aims to manufacture the fastest world train. The idea of this train is to move through a tunnel evacuated from air to omit friction between the train and air because of the absence of air.

Write a research about that type of trains and the possibility of using them in Egypt.



Third - Questions and Exercises

(1) If a train suddenly moved forwards, to which direction a bag beneath a chair would move?

....

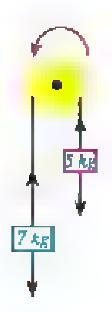
(2) Explain this saying: "Newton's first law is a special case of Newton's second law"

....

(3) What is the weight of a space probe of mass 225 kg on moon, assuming that acceleration due to gravity on moon = $1.62\ m/s^2$?

....

(4) Evaluate the acceleration by which two loads fall freely, the mass of the first load = 5 kg and the other = 7 kg, neglecting the air resistance.



....

....

(5) An astronaut projected a small object in a certain direction. What would happen to the astronaut as a response to his action? Accordingly, suggest a method to change the direction of a spaceship outside the atmosphere.

....

6 Choose the correct answer for each phrase of the following:

1 When the resultant force acting on a moving car is zero, the car ....

a. moves at positive acceleration. b. moves at negative acceleration.

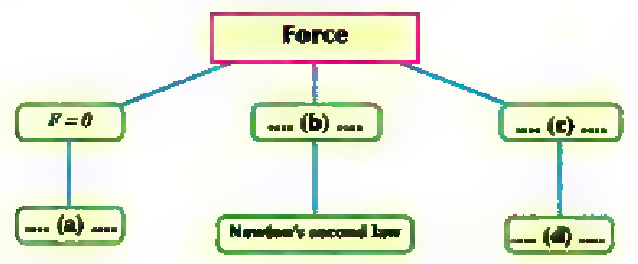
c. moves at uniform velocity. d. stops motion .

2 Newton's third law of motion can be expressed mathematically as ....

a. $\Sigma F = 0$ b. $\Sigma F \neq 0$

c. $F = m a$ d. $F_1 = - F_2$

7 Complete what is missing in the following concept map:



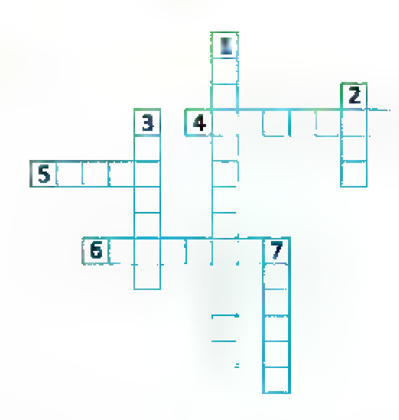
8 Enjoy crosswords:

Across:

(4) Newton's law that states that: A static object keeps its state of rest, and a moving object keeps its state of motion at uniform velocity in a straight line unless acted upon by a resultant force.

(5) An external influence that affects the object to change its state or direction of motion.

(6) Newton's law that states that: For every action there is a reaction equal in magnitude and opposite in direction



Down.

(1) The tool used to measure force.

(2) Resistance of object to change its kinematic state.

(3) Tendency of an object to keep either its state of rest or state of motion at its original velocity uniformly in a straight line.

(7) The force of gravity acting on the body.

General Exercise on the Second Unit

① Choose the correct answer for each phrase of the following:

1 A bicycle moves at uniform velocity in a straight line to East when the resultant force on the bicycle is ....

a. zero
b. negative
c. positive.
d. towards east.

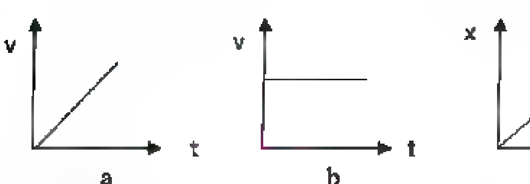
2 When an object is projected at initial velocity in a direction making an angle 60° to the horizontal to reach a horizontal range R. To make the projectile reach a greater range, it should be projected at the same initial velocity and angle ....

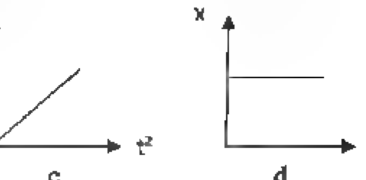
a. 90°
b. 75°
c. °45
d. 30°

3 An object moves at uniform acceleration when ....

a. It covers equal displacements in equal times.
b. Its velocity decreases with equal amounts in equal times.
c. Its velocity decreases with equal amounts in unequal times.
d. The resultant force acting on the object is zero

4 The graph that best describes the motion of an object at uniform velocity is ...

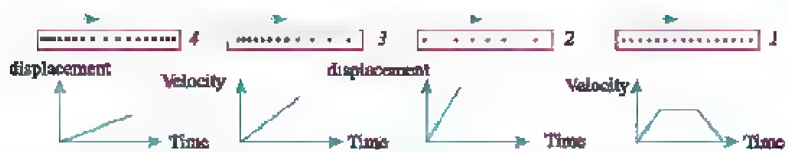




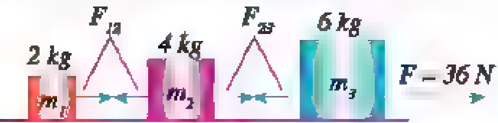
5 When the direction of acceleration is opposite to the direction of velocity, ...

a. resultant force decreases.
b. object velocity increases.
c. object velocity is unchanged.
d. object velocity decreases.

2. You have four ticker-tapes that describe the motion of objects. Match each ticker-tape with the proper graph that represents the same motion.



3. Three masses are connected together by weightless threads as shown in figure. They are pulled on a smooth surface by a horizontal force. Find:

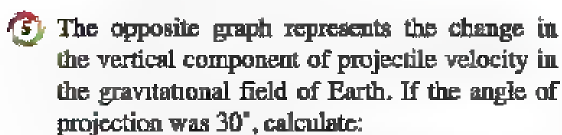


- The common acceleration of these masses
- The tension force in each thread.

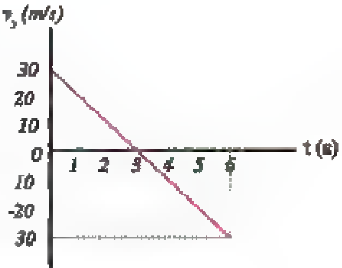
4. An elephant pulls a wooden lump of mass 0.5 ton by a rope along the ground at uniform velocity given that the rope makes an angle 60° to the horizontal as shown in figure.
Given that the friction force between the lump and ground is 200 N, find:

- The tension force in the rope.
- The tension force in the rope required to make the lump move at acceleration 2 m/s^2.

5. The opposite graph represents the change in the vertical component of projectile velocity in the gravitational field of Earth. If the angle of projection was 30°, calculate:



- The velocity by which the object was projected
- Maximum height reached by the object.
- The horizontal range.



6. Use the data given in figure to find the projection velocity of a cannonball that is required to hit the ship. ($a = 10\ m/s^2$)

In a nutshell

First: Main Concepts

- **Motion :** the change in the position of an object relative to another object with time.
- **Velocity:** the displacement of the object in one second.
- **Acceleration:** the change in the object velocity in one second.
- **Free fall acceleration:** the uniform acceleration by which objects fall freely towards Earth's surface.

Second: Main Relationships

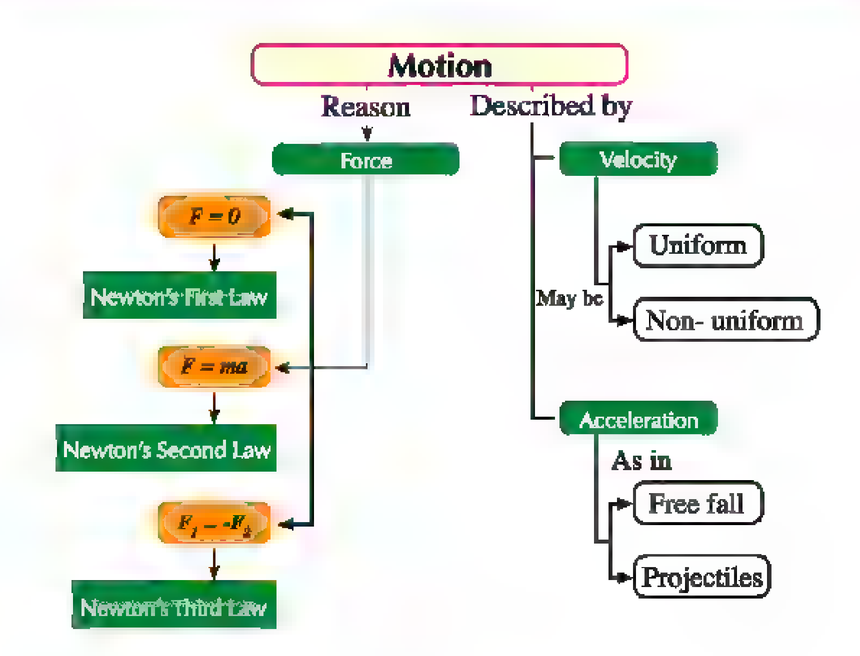
$$v_f = v_i + at \qquad d = v_i t + \frac{1}{2} at^2 \qquad 2ad = v_f^2 - v_i^2$$

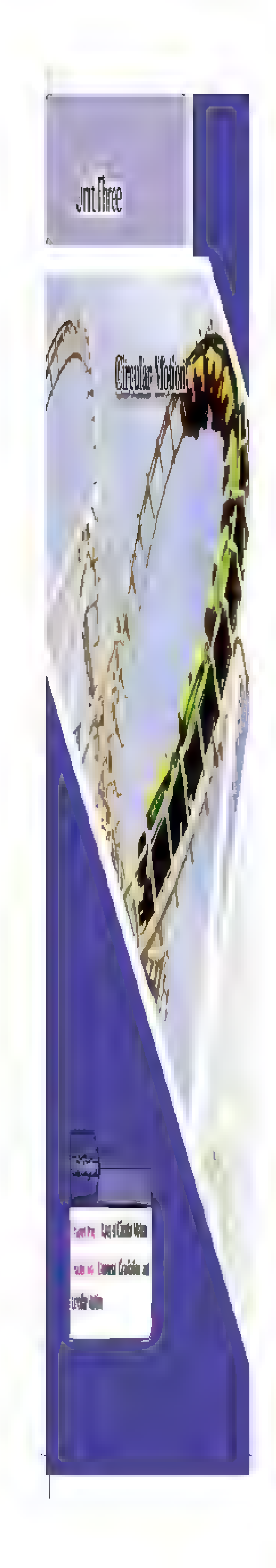
$$v_{ix} = v_i \cos\theta \qquad v_{iy} = v_i \sin\theta$$

Third: Main Laws

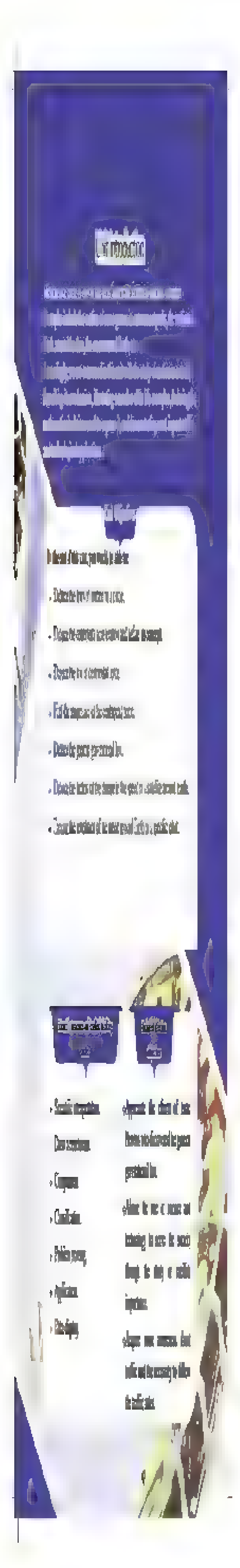
- **Newton's First Law of motion:** "A static object keeps its state of rest, and a moving object keeps its state of motion at uniform velocity in a straight line unless acted upon by a resultant force.". $\sum F = 0$
- **Newton's Second Law of motion:** "When a resultant force affects an object, the object acquires an acceleration which is directly proportional to the resultant force and inversely to the object mass." $\sum F = ma$
- **Newton's Third Law of motion:** "For every action there is a reaction equal in magnitude and opposite in direction.". $F_1 = -F_2$

Mind Map


Motion
Reason
Described by
Force
F = 0
Newton's First Law
F = ma
Newton's Second Law
F1 = -F2
Newton's Third Law
Velocity
May be
Uniform
Non- uniform
Acceleration
As in
Free fall
Projectiles



Unit Three
Circular Motion



Chapter One

Laws of Circular Motion

Expected Learning Outcome

By the end of this chapter you will be able to:

- Deduce the laws of circular motion.
- Deduce the value of the centripetal acceleration and define its concept.
- Deduce the law of centripetal force.

Physical Terminology

- *Circular Motion*
- *Centripetal Acceleration*
- *Centripetal Force*

Learning Resources

- Educational video: introduction to motion in a circle
  http://www.youtube.com/watch?v=PBpe LLiQJw
- Practical demonstration: Law motion in a circle
  http://www.youtube.com/watch?v=Juz9m0BFX0I

Through your study to Newton`s second law, you learned that when a force acts on a body moving at a certain velocity, the body acquires an acceleration, i.e a change in its velocity takes place. This change depends on the direction of the acting force relative to the direction of motion as fallows:

When a force acts on a moving body

and

The direction of force is in the same direction of motion.	The direction of force is opposite to direction of motion	The direction of force is normal to that of motion
The magnitude of velocity increases & its direction does not change	The magnitude of velocity decreases & its direction does not change	The direction of velocity changes and its magnitude does not change

When racer (2) in figure (1) pumps more fuel, a force acts on his motorbike in the same direction of motion that increases its velocity, but if he applies the brakes, the force will be in an opposite direction to the direction of motion that decreases its velocity. But when racer (1 or 3) leans his body to right or to left, a force is generated normal to the direction of motion. Thus, the direction of motion is changed and the racer moves in a circular path.

Fig (1). Motion in curved paths

Mini Lab

Motion in a circle

- Let a stone be attached to a string. Hold the other end by your hand, then whirl the stone around in a circle. Increase the velocity of the stone during rotation. What do you notice? Let the stone go freely, in which direction will the stone go?

(Demonstrating Motion in a Circle)

From the previous, we conclude that:

- For body to move in a circle , a force (F) normal to its direction of motion and directed towards the centre of the circle has to act on the body to force it to continue its circular motion.
- If this force is removed, the body will rush in the direction of the tangent to the circular path, at the point where the force is removed at a constant velocity in magnitude and direction and moves in a straight line. This velocity is called tangential velocity (v).

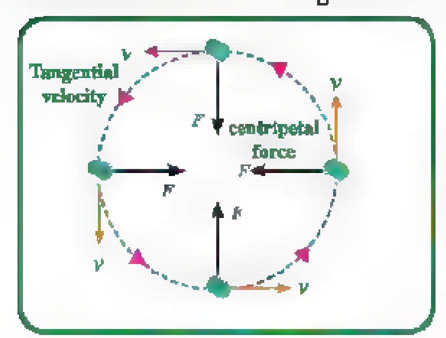


Figure (2): Direction of force & velocity in the circular motion

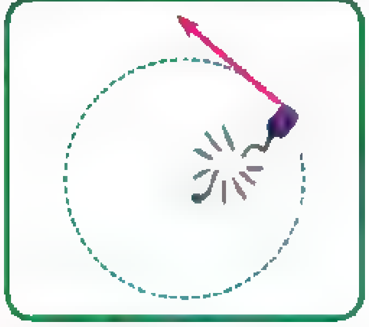


Figure (3): Direction of body motion when the string is cut

- **Uniform circular motion:** it is the motion of a body in a circular path at a constant speed but changeable direction. The force acting on this body towards the center is called The centripetal force.
- **Centripetal force:** it is the force acting continuously in a direction normal to the motion of a body, Accordingly, its path changes from being straight into circular.

Mini Lab

Centripetal force:

Figure (4): Why doesn't water fall from the bucket?

- Fill a bucket to its half with water and move it in a vertical circle at sufficient velocity, does the water fall from the bucket?
- This can be explained as follows: the centripetal force acting on water is normal to the direction of motion. Thus, the force changes the direction of velocity without changing its magnitude. So, water rotates in a circular path with the bucket and is kept inside.

1- Types of Centripetal Force

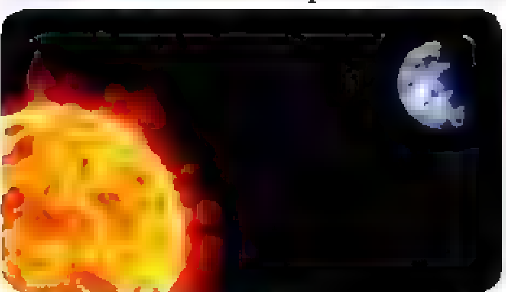
Fig (5): Why does the gymnast feel a tension force in her arms during rotation?

Centripetal force is not considered as a new type of force. Simply, it is the term given to any force acting normally to the path of moving a body and makes it move in a circular path. May the centripetal force be tension force, or gravitational force. Some examples for these forces are given in the following section:

1-1 Tension force (F_T): on pulling a body using a string or a wire , a tension force is originated in the string When this force acts normal to the direction of motion at constant speed, the body moves in a circular path The tension force acts as a centripetal force

Fig (6): Tension force in the string acts as a centripetal force.

1-2 Gravitational force (F_G): A gravitational force exists between the Earth and the Sun. This force is normal to the direction of motion of the Earth. This is why the Earth moves in a circular path around the Sun.



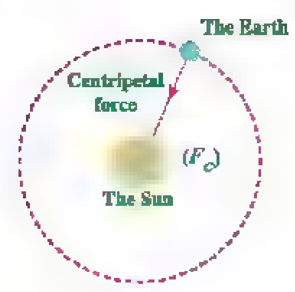


Fig (7): The gravitational force acts as a centripetal force

1-3 Friction force (F_f): when a car turns in a circular path or a curve, a friction force between the road and the car tyres is originated. This force is normal to the direction of the car motion toward the centre of the circle. Thus the car moves in the curved path.

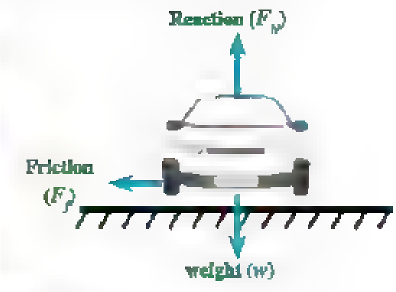
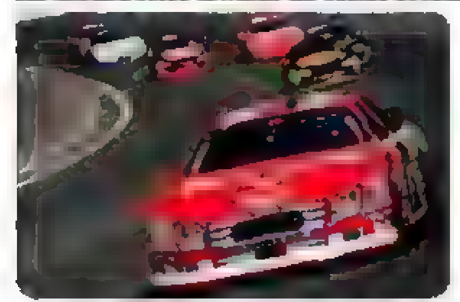


Fig (8): Friction force acts as a centripetal force

1-4 Reaction force (F_R): the reaction force always acts normally on the car. If the circular path of the car is inclined at an angle to the horizontal, a horizontal component for the reaction force is produced towards the centre of the circle that helps turning the car. In this case, the centripetal force is the sum of the two components of the reaction force and the friction force towards the centre of rotation



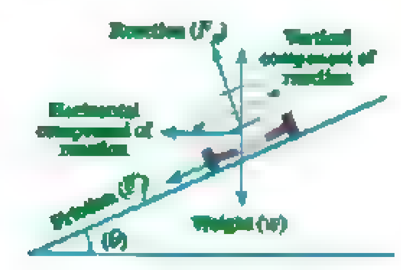
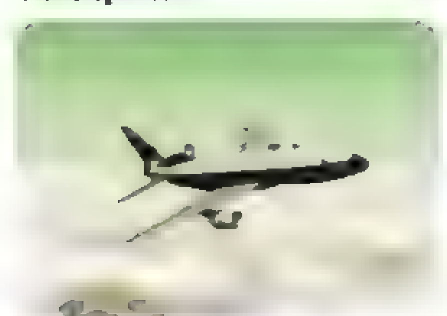


Fig (9): the centripetal force is the sum of the two components of reaction and friction in the horizontal direction

1-5 Lifting force (F_L): The lifting force always acts normally to the body of an aeroplane. When the aeroplane inclines, a horizontal component of the lifting force is produced towards the center of the circle. This force is considered as the centripetal force affecting the aeroplane.



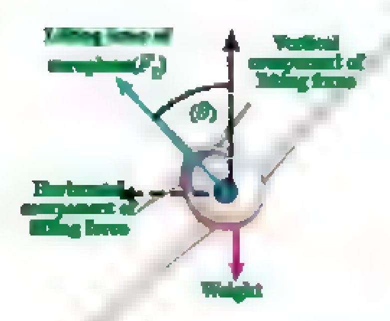


Fig (10) The horizontal component of the lifting force on the aeroplane acts as a centripetal force

2-Centripetal Acceleration

When a force (F) acts normally to the direction of body motion that has mass (m) moving at velocity (v) in a circular path of radius (r), a change in the direction of its velocity happens. Accordingly, the body will acquire an acceleration (a) called the centripetal acceleration. Its direction is the same as the direction of the centripetal force.

Looking at figure, it is obvious that each of velocity (v), force (F) and acceleration (a) has its constant magnitude but is continuously changing its direction.

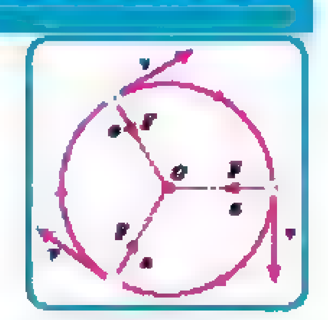


Fig (11) : Velocity vector and acceleration vector in uniform circular motion.

Centripetal acceleration (a): It is the acceleration acquired by the body in a circular motion due to a change in the direction of its velocity.

In fig. (12), it is noticed that as the body moves from point *(A)* to point *(B)*, the velocity *(v)* changes in direction, but magnitude maintains. Thus, the change in velocity *(Δv)* results due to the change in the direction of velocity only.

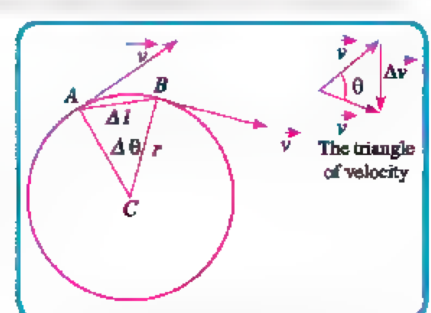


Fig.(12) : Motion of body from (A) to (B)

Calculating the centripetal acceleration:

Through the similarity of the triangle *(CAB)* and the triangle of velocities shown in figure *(12)*, the following relation can be obtained:

$$\frac{\Delta l}{r} = \frac{\Delta v}{v} \qquad (1)$$

where Δv is directed towards the centre of the circle

$$\therefore \Delta v = \frac{\Delta l}{r} \cdot v \qquad (2)$$

If the body transfers from point *(A)* to point *(B)* in a a period of time *(Δt)*, the centripetal acceleration *(a)* can be calculated by dividing equation *(2)* by *(Δt)*:

$$\therefore a = \frac{\Delta v}{\Delta t} = v \frac{\Delta l}{\Delta t} \frac{1}{r}$$

Since $\frac{\Delta l}{\Delta t}$ equals (v), then the centripetal acceleration equals.

$$\therefore a = \frac{v^2}{r} \qquad (3)$$

Calculating the value of the centripetal force (F):

According to Newton's second law , the force is given by the relation *(F=ma)*, i.e:

Centripetal force in uniform circular motion = mass × centripetal acceleration

Substituting the value of centripetal acceleration from relation (3), we find that:

$$\therefore F = m \times \frac{v^2}{r} \qquad (4)$$

Calculating the value of the tangential (linear) velocity (v):

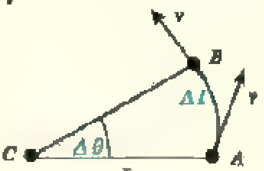
Assume that a body made a complete circular revolution during a time interval *(T)*. This time is called periodic time. During this time, The body moved a distance equals the circumference of the circle *($2\pi r$)*. Thus the tangential velocity (velocity of rotation) can be calculated by:

$$v = \frac{\text{distance}}{\text{time}} = \frac{2\pi r}{T}$$

This means that the tangential (linear) velocity can be calculated by knowing each of the periodic time *(T)* and the radius of circular path *(r)*.

Enrichment Information

➡ If a body moves at a tangential velocity (v) in a circle of radius (r) from point (A) to point (B), covering a distance (Δl) corresponding to an angle ($\Delta\theta$), during time (Δt), the value ($\frac{\Delta\theta}{\Delta t}$) is known as the angular velocity (ω).



$$\omega = \frac{\Delta\theta}{\Delta t} \qquad (1)$$

It is known that the measure of an angle in radians equals the ratio of the arc length to the radius of the path.

$$\Delta\theta = \frac{\Delta l}{r}$$

Substituting the value of ($\Delta\theta$) in equation (1), we find that:

$$\omega = \frac{\Delta l}{\Delta t} \times \frac{1}{r} = \frac{v}{r}$$

$\therefore v = \omega r$

$\therefore$ Tangential velocity = angular velocity× radius of path

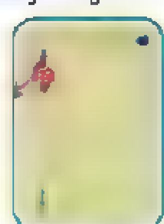
Since $v = \frac{2\pi r}{T}$

$\therefore \omega r = \frac{2\pi r}{T}$ $\qquad \therefore \omega = \frac{2\pi}{T}$

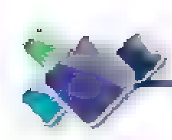
Mini Lab

Verification of the centripetal force:

- Attach a cork stopper of mass (m) to a string, then pass it through a metallic or plastic tube (like: a pen tube), then attach the other end to a weight of mass (M).
- When we rotate the piece of cork in a circular path, the centripetal force is originated from the tension force in the string (F_T) which is equal to the weight of the hanged mass i.e $F = F_T = Mg$
- By using the previous tools and a stopwatch, the relation can be verified experimentally $= Mg = m\frac{v^2}{r}$



Tools of the experiment



Solved Example

In the previous experiment, the mass of the cork stopper was *(13g)* and it was rotated in a horizontal circular path of radius *(0.93 m)* to make *(50 revolutions)* in time *(59 s)*. Calculate the mass of the load attached to the string.

Solution:

Calculating periodic time:

$$T = \frac{\text{Total Time}}{\text{No of revolutions}} = \frac{59}{50} = 1.18\ s$$

Calculating velocity:

$$v = \frac{2\pi r}{T} = \frac{2 \times 3.14 \times 0.93}{1.18} = 4.9\ m/s$$

Calculating tension force:

$$F = m\frac{v^2}{r} = 0.013 \times \frac{(4.9)^2}{0.93} = 0.34\ N$$

Calculating mass of the load:

$$M = \frac{F}{g} = \frac{0.34}{9.8} = 0.035\ kg$$

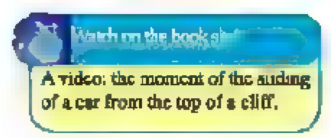
Factors affecting the centripetal force:

It is necessary to calculate the centripetal force when designing a curve in roads or railways in order to help cars and trains move along this curved path without skidding. Through studying the relation (4), we can conclude that the centripetal force depends on each of the following factors:

1 - Mass of the body (m): where the centripetal force is directly proportional to mass.

The force required to move a bicycle in a curved path is less than that required to move a truck in the same path. This explains why trucks are not allowed to move along some dangerous curves.

Fig (13) : It is not allowed for trucks and trailers to move on some dangerous curves. Explain why?



2-Tangential velocity (v): where the centripetal force is directly proportional to the square of velocity. When the velocity of a car increases , it needs more centripetal force to move within a curved path. So engineers define a certain velocity which should not be exceeded for the motion in curves road and highway.

Fig (14) : Maximum velocity on this curve is (80 km/h)

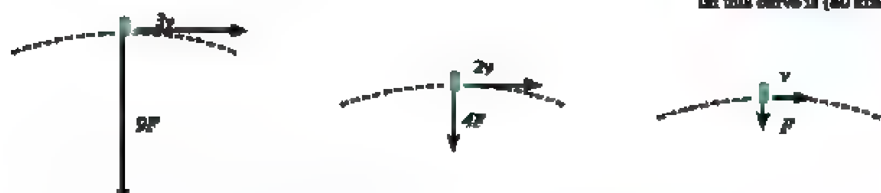


Fig. (15) : The effect of the change in velocity of a body, moving in a curved path , on the value of the centripetal force.

3- Radius of rotation (r) : where the centripetal force is inversely proportional to the radius of the path. i.e , when the radius of curve decreases , the car needs more centripetal force to keep moving in a circle. Accordingly the curve becomes more dangerous. To avoid sliding out , it is advisable to move with low speeds in dangerous curves.

Fig (16) : Why is the maximum velocity *(40 km/h)* on the curve of smaller radius while it is *(60 km/h)* on the curve of greater radius?.

What is the effect of the decrease in the centripetal force on the radius of rotation?

when the centripetal force decreases , this means that the radius will increase , because ($F \propto \frac{1}{r}$) , i.e , the body will be moving away from the center of the circle. If the centripetal force becomes zero , the body will move in a straight line because of inertia.

Assume that a car moved on a curved path, and the road has oil stains, friction forces are not enough to rotate the car within the curved path which causes the car to skid. The tires creep on the bypath and the car can not keep moving in the curved path.

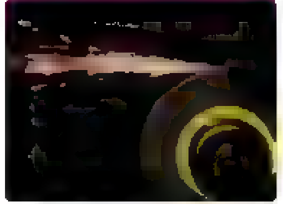


Fig (17) : Why do metal splints rush straight at tangential velocities when using the electric sharpener?

Centripetal force — The car skids

The force is not enough for rotation

Centripetal force

Force is enough for rotation

Fig (18): If the centripetal force is not sufficient, the car will skid out of the curved path

Activity [illegible]

Visit the traffic administration in your governorate to recognize the efforts done by traffic officers to serve citizens. Also to know the main reasons for road accidents [illegible]

Applications

- [illegible] away from the circular path when the centripetal force is too weak to keep them in the path can be used in many life applications such as drying clothes, candy floss, and the rotating barrel in the amusement park. For instance, water droplets adhered to clothes with certain forces. When the dryer tub rotates at high speeds, the [illegible] becomes insufficient to keep water droplets rotating. Accordingly they eject tangential to the circular path and separate from clothes.

Fig (19): When the drier rotates at a great velocity, water droplets are expelled tangential to the circumference of the tub

Solved Example

A stone of mass ([illegible] g) is attached to a string of length ([illegible] cm), rotating at velocity ([illegible] m/s). Calculate the centripetal force. What do you expect if the maximum tension force that the string can afford is ([illegible] N)?

Solution:

Calculating the centripetal force:

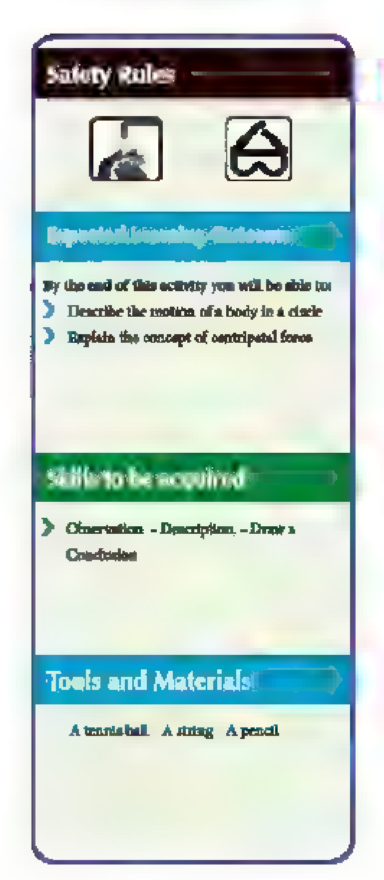
$$F = m\frac{v^2}{r} = [illegible]$$

Since the required centripetal force is more than the maximum tension force that the string can afford, the string will be cut. The stone moves in a straight line at the moment of cutting the string tangent to the circular path.

Activities and Exercises

Chapter One

Laws of Circular Motion



First- Practical Experiments

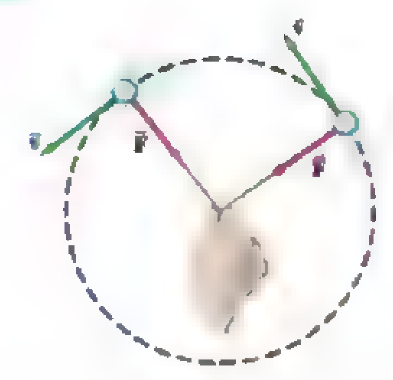
(1) Demonstration of motion in a circle:

Experiment overview:

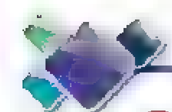
We have learnt that a force towards the centre is required to move a body in a circular path and is known as "centripetal force".

This experiment aims to describe the motion of a rotating body in a circular path, and to realize the concept of the centripetal force.

Procedure:



1. Attach a tennis ball to one end of a string, and let the rest of the string free having an appropriate length (about 120 cm).
2. Using a pencil, draw a circle of a suitable radius.
3. Put the ball at a point on the circle circumference.
4. Hold the free end of the string at the center of the circle.



5. Rotate the ball with a suitable velocity so that it moves along the circumference of the drawn circle.
6. Repeat the previous step with different lengths (25 50 75 100 cm). Ask for the assistance of your colleagues.
7. Set the string suddenly free from your hand and then register the direction in which the ball moved.

Remarks:

Length of the string	Description of motion
25 cm	....
50 cm	....
75 cm	....
100 cm	....

- Did you feel the necessity of pulling the string to the centre to keep the ball rotating in its path? (Yes / No).
- When you suddenly freed the string, did you notice that the ball continued motion in the circular path, or it was launched in a straight line along the direction of the tangential (linear) velocity?

  ....

  ....

  ....
- Draw an arrow from the point on the circle circumference in the direction of the ball motion where you freed the ball.

  ....

  ....

  ....
- Explain the results that you have got.

  ....

  ....

  ....

Second – Evaluation Activities

1. Explain the idea of operation of the centrifuge devices that depend on the principles of motion in a circle. Then, show some of its uses in different fields, such as: separating blood cells from the plasma, separating uranium from impurities in the process of Uranium enrichment, and separating the cream from milk.

(2) Cooperating with your colleagues, design a device as that shown in the figure. It consists of a rigid metallic wire that passes through two holes in two balls; one of them is a light plastic ball while the other is a heavy iron ball. Then rotate the wire using a small electric motor. Which ball will rise upwards higher than the other? Why?

(3) Design the apparatus shown in the figure by mounting the center of a ruler on the axis of a small electric motor. Fix the electric motor on a wooden base and connect the electric motor to a battery. Use this apparatus to study the relation between the centripetal force and each of the rotation radius and mass.

Third - Questions and Exercises

(1) Complete the following statements with suitable answers:

a. In the uniform circular motion, the direction of centripetal acceleration is always towards ...., and the centripetal force is in the direction of......... No change happens in the .... but a change takes place in ....

b. In a uniform circular motion, the constant force that acts normally to the direction of linear velocity is called .. ..

c. In a uniform circular motion, the tangential velocity of a body is characterized by .... and ... .

d. The magnitude of the centripetal acceleration during a uniform circular motion depends on .... and ....

(2) Give reasons for:

a. Although a body moving in a uniform circular motion is affected by a centripetal force towards the center, it never gets closer to the center of the circle.

....

b. At curves, the motorbike rider tilts his bike and body towards the center of the circular path.

....

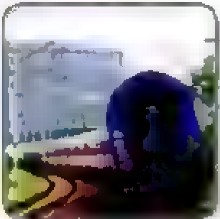
c. When a car moves in a road curve, it maintains its curved path and doesn't skid.

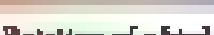
....

3. A body of mass 100 gm moves along the circumference of a circle of radius 50 cm at a uniform circular motion. It takes a time of 90 s to make 45 complete revelations.

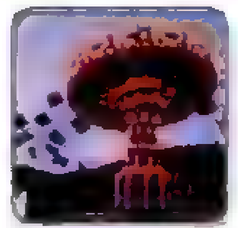
Calculate: a. Periodic time. b. Linear velocity. c. Centripetal acceleration.

4. Determine the type of centripetal force in each of the following cases; (gravitational pull – electric attraction – tension force – reaction force – lifting force):





Rotation of a bird



Rotation in flying chairs

Turning of a train

5. On rotating a stone attached to the end of a string in a circular path. What is the direction of the force affecting on the stone? What is its benefit? What is the direction of motion if the string is cut?

6. What is the direction of force by which the safety belt affects on the car driver when the car turns?

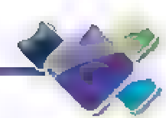
7. A body of mass 2 kg is attached to the end of a string to rotate in a horizontal circular path of radius 1.5 m, so as to make 3 revolutions in one second, calculate:

a. Linear (tangential) velocity.

b. Centripetal acceleration.

c. Tension force in the string.

8. A car of mass 1000 kg is moving at a constant speed of 5 m/s around a curve of radius 50 m. Calculate the centripetal friction force that keeps the car moving around the curve.



(9) A bicycle rider moves in a circular path at a tangential velocity of 13.2 m/s. If the radius of the path is 40 m, and the force keeping the bicycle in a circular path equals 377 N, Calculate the mass of both the bicycle and the rider.

....

....

(10) A racing car of mass 905 kg moves in a circular path of perimeter 3.25 km. Calculate the tangential velocity of the car if the force required to keep the circular motion of the car = 2140 N.

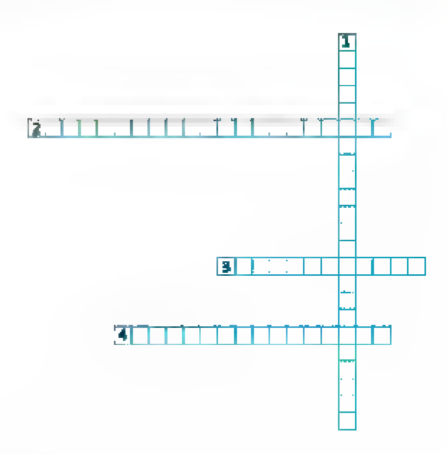
....

(11) Would the water be kept inside the bucket when you rotate it in a vertical plane as shown in the figure? Explain your answer.

....

....

(12) Enjoy crosswords:



Cross:

(2) The motion of a body in a circular path at a constant speed but of changeable direction.

(3) The time taken by the body to cover the circumference of a circle.

(4) The force that continuously acts normally to the motion of a body, changing its straight path into circular.

Down:

(1) The acceleration acquired by a body in circular motion due to a change in the direction of velocity.

Chapter Two

Universal Gravitation and Circular Motion

At the end of this chapter you will be able to :

- Deduce the universal gravitation law
- Explain the rotation of the moon around the Earth in a constant path
- Deduce the factors affecting the change of velocity of a satellite during its motion around Earth.

Expressions of the ch

- *Universal gravitation.*
- *Gravitational constant.*
- *Gravitational filed.*
- *Intensity of the gravitational filed.*
- *Satellite.*
- *Critical velocity.*

Electronic sources of learning!

- **Educational video:** introduction about law of universal gravitation.
- **Electronic game:** Satellite principle.

1- Newton's Law of Universal Gravitation

The universe is always in a continuous motion. The moon revolves around the Earth which in turn revolves around the sun that rotates around the centre of the galaxy .

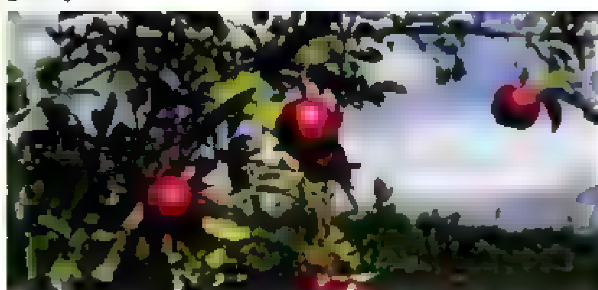
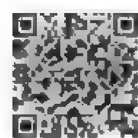


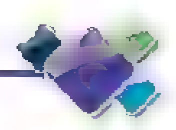
Fig (20) : Through Newton's first law of motion, the falling of a motionless apple indicates the presence of a force that affected it.

The links below explains how the universal gravitation has been discovered



Newton studied the nature of this attracting force , and concluded that this force depends on the masses of the attracted bodies and the separating distance, as follows:

A body in the universe attracts any other body by a force, this force is directly proportional to the product of their masses and inversely proportional to square the distance between their centers.

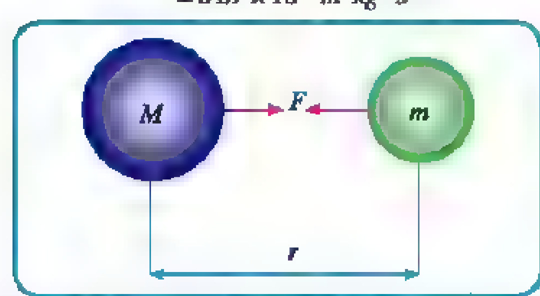


This law is formulated as fallows:

$$F = G\frac{Mm}{r^2} \qquad (1)$$

where (r) is the distance between the centers of the two bodies , (G) is the proportionality constant which is a universal constant know as "The gravitational constant" , it equals:

$$G = 6.67 \times 10^{-11} N.m^2\,kg^{-2}$$
$$= 6.67 \times 10^{-11} m^3\,kg^{-1}\,s^{-2}$$



It is worth to mention that the gravitational force is a mutual force between two bodies, each one attracts the other by the same force. Because of the generality of this law it is known as the law of universal gravitation.

Distinguished Scientists

Arab scientists had a great role in developing astronomy and getting benefits of it. One of those scientists was Al - Biruni (Abu Al Reihan Mohammed) , who succeeded in calculating the circumference of Earth. Others include Astolabe Ali-Ben Bissa and Ali Al-Buhtury.

Fig (21) Abu-Al-Reihan Al Biruni

Solved example

Two small balls of mass (7.3kg) each, are separated by a distance 0.5 m between their centres. Calculate the mutual attraction force between them, then write an appropriate comment.

Solution:

Through the universal gravitation low, the attraction force equals:

$$F = \frac{G\,Mm}{r^2} = \frac{(6.67 \times 10^{-11})\,(7.3)^2}{(0.5)^2}$$

$$F = 1.4 \times 10^{-8}\,N$$

In this example, we notice that the mutual attraction force between the two balls is very small that it is equal to the weight of a sand grain on the beach.

Enrichment Information

- We notice that the value of the gravitational constant is very small. That is why the force of attraction between bodies is not noticeable, or large unless these bodies are either massive, the separating distance between these bodies are small, or both.

2- Gravitational Field

We have learned that the gravitational force is inversely proportional to square the distance between two bodies. Accordingly, force decreases strongly until the distance between these two bodies get so big that a point is reached where the effect of attraction between them vanishes

Within this distance, there are attraction forces. So the gravitational field is known as: «the space in which the gravitational forces appear.»

The intensity of Earth's gravitational field:

It is the attraction force of Earth to a mass of (1kg). It is denoted by (g), and numerically equal to the acceleration due to gravity. By applying the universal gravitational law, we find that:

$$g = \frac{GM}{r^2} \qquad (2)$$

Where (M) is the mass of the earth. $= 5.98 \times 10^{24}\ kg$

$r = R + h$

(R) is the radius of Earth ($R = 6378 km$)

(h) is the height above the earth's surface.

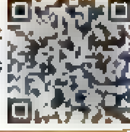
Through relation (2), conclude the factors affecting the value of acceleration due to gravity.

Through the book site on the internet:

Contact your colleagues, teachers and book authors

Go Further

For more knowledge about this topic you can refer to the Egyptian Knowledge Bank (EKB) through the opposite link.



Satellites

Man has dreamt to explore the space. He continued to develop probs and rockets that launch space ships to rotate around the Earth, or to reach further, (for example, to reach another planet like Mars).

On the 4th of October 1957, the world received the surprise of sending a satellite (Sputnik) to the space as the first space follower for the earth. That was followed by human success in sending other satellites. Moreover, he succeeded to put foot on the moon. Space exploration still continues successfully.

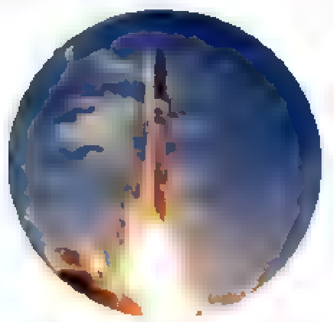


Fig (22) : Launching a rocket to put a satellite in orbit.

Fig (23) : A satellite rotating around the earth.

Idea of launching the satellite:

Issac Newton is considered to be the first one who explained the scientific base of launching satellites. He imagined that on projecting a projectile in a horizontal plane from a mountain peak, it will fall freely and take a curved path towards the earth. If the velocity of projection increases, the projectile will reach the earth at a further point and follow a less-curved path. And when the curvature of the projectile path is parallel to the curvature of the Earth's surface, it will rotate in a particular path, and become an Earth's follower. Its rotation will be similar to the moon's rotation around the earth. That's why it is called a *satellite*.

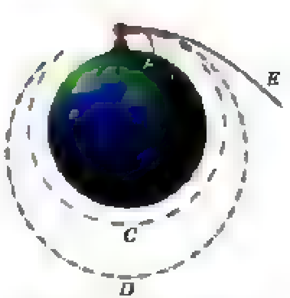


Fig (24): Launching a projectile in a horizontal plane, it will take a curved path.

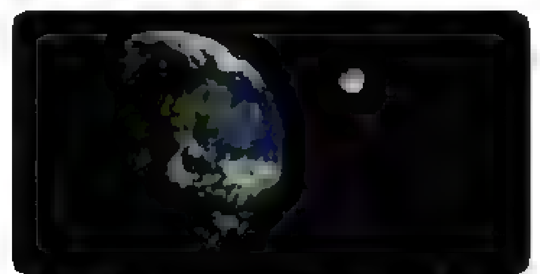
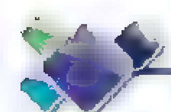


Fig (25): The moon rotates around the earth in a particular path.



What happens when. ?

- **The satellite stops and its velocity becomes zero:** It would fall in a straight line towards the earth and fall onto it.
- **The gravitational force between the earth and the satellite vanishes:** The satellite moves in a straight line along the tangent to the circular path, and move getting away from the Earth.

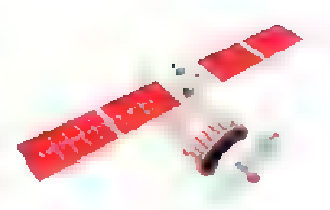


Fig (28) : A satellite

Finding the orbital velocity of the satellite:

Assuming that there is a satellite of mass (m), moving at a constant velocity (v) in a circular path of radius (r), around the earth whose mass (M) as shown in the figure:

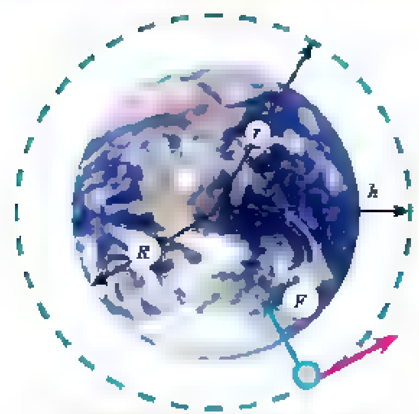


Fig (26) . The satellite path around the earth

We notice that the gravitational force between the earth and the moon is normal to the motion of the moon, and it keeps the moon in a circular orbit. i.e The force of gravitation between the moon and the earth acts as a centripetal force:

i.e:
$$F = m\frac{v^2}{r} = G\frac{mM}{r^2}$$

$$m\frac{v^2}{r} = G \times \frac{mM}{r^2}$$

From the previous equation, it is clear that the satellite velocity in its orbit:

$$v = \sqrt{G\frac{M}{r}} \qquad (2)$$

The value of velocity (v) in equation (2) represents the velocity required to keep the satellite rotate around the earth.

If the height at which the satellite is launched into space is (h), so, r = R + h.

Where (R) is the radius of the Earth.

Factors affecting the change in velocity of a satellite during its motion arround the earth:

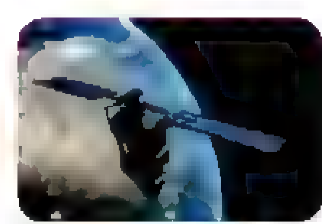


Fig (27): A satellite arround the earth.

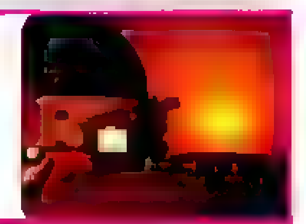
From relation (2), it is clear that the velocity of the satellite in its orbit does not depend on its mass; but it depends on the following factors:

- The mass of the planet around which the satellite rotates.
- The height of the satellite away from the center of the planet arround which it rotates.

Enrichment Information

- As the mass of the satellite to be sent into the space increases, we need a rocket of more power to launch the satellite away into the space in order to gain the velocity required for it to orbit Earth.

Activities



Visit one of the astronomical observatories, like Helwan Observatory (National institute for Astronomical and Geophysical Researches), to recognise the nature of work inside the observatory and to collect information about satellites and how they are sent into the space.

Solved examples

1 The moon rotates arround the earth in a circular orbit whose radius is (3.85×10^5 km). It makes a complete revolution through (27.3 days). Calculate the mass of the earth (Universal gravitation constant $16.67 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$)

Solution.

Periodic time: $T = 27.3 \times 24 \times 60 \times 60 = 2.36 \times 10^6\ s$

velocity of the moon:

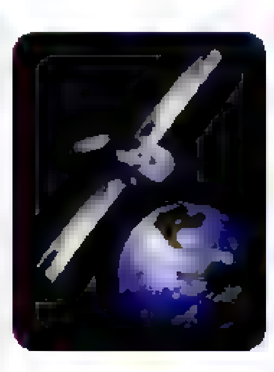
$$v = \frac{2\pi r}{T} = \frac{2 \times 3.14 \times 3.85 \times 10^5 \times 10^3}{2.36 \times 10^6} = 1025\ m/s$$

Mass of the earth:

$$v^2 = G\frac{M}{r}$$

Therefore:

$$M = \frac{v^2 \times r}{G} = \frac{(1025)^2 \times 3.85 \times 10^5 \times 10^3}{6.67 \times 10^{-11}} = 6 \times 10^{24}\ kg$$



2 A satellite rotates around the earth in almost circular path at a height of *(940 km)* away from the earth's surface. Calculate the orbital velocity, the time required by the satellite to make a complete revolution around the earth, knowing that

$(R = 6360 \text{ km}, M = 6 \times 10^{24} \text{ kg}, G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2)$

Solution

Calculating the radius of rotation of the moon around the earth .

$$r = R + h = 6360 + 940 = 7300 \text{ km} = 7.3 \times 10^6 \text{ m}$$

Calculating the orbital velocity:

$$v = \sqrt{G\frac{M}{r}}$$

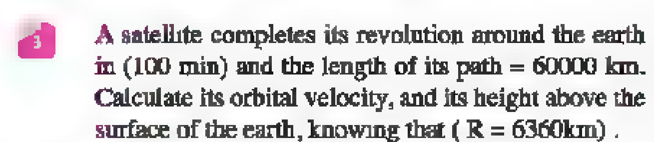
$$v = \sqrt{6.67 \times 10^{-11} \frac{6 \times 10^{24}}{7.3 \times 10^6}}$$

$$v = 7.4 \times 10^3 \text{ m/s}$$

Calculating the periodic time:

$$v = \frac{2\pi r}{T}$$

$$T = \frac{2\pi r}{v} = \frac{2 \times 3.14 \times 7.3 \times 10^6}{7.4 \times 10^3} = 6195 \text{ s}$$



3 A satellite completes its revolution around the earth in (100 min) and the length of its path = 60000 km. Calculate its orbital velocity, and its height above the surface of the earth, knowing that (R = 6360km) .

Solution

Calculating velocity of the moon:

$$v = \frac{2\pi r}{T} = \frac{43120 \times 10^3}{94.4 \times 60} = 7613 \text{ m/s}$$

Calculating height of the moon away from the earth.

$$2\pi r = 43120 \times 10^3$$

$$r = \frac{43120 \times 10^3}{2 \times \pi} = 6.86 \times 10^6 \text{ m} = 6860 \text{ km}$$

$$r = R + h$$

$$h = r - R = 6860 - 6360 = 500 \text{ km}$$

Importance of satellites

Usage of satellites has made a real revolution in many fields. The satellite is considered as a very high tower used in sending and receiving the wireless waves. There are many kinds of satellites, some of them are :

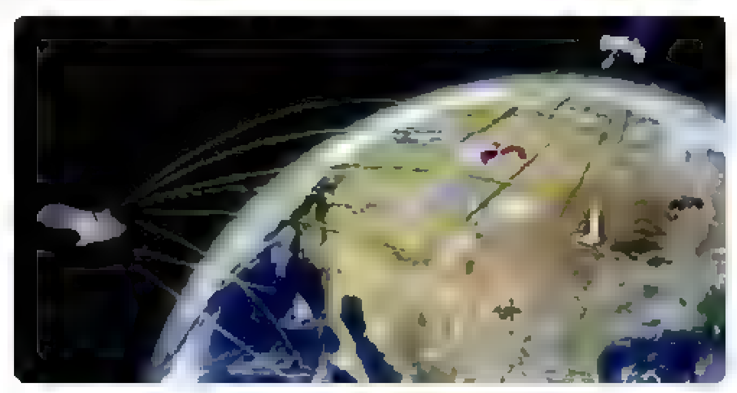
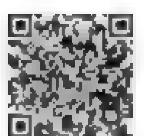


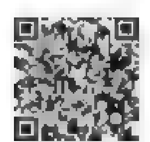
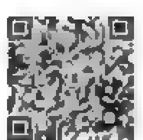
Fig (28) : Satellites have many benefits in different fields

- Communication satellites: They transmit phone calles, radio and TV signals to and everywhere on the earth s surface.
- Astronomical satellites : they are huge telescopes roaming in the space, and they can image the orbs accurately.
- Remote sensing satellites: they are used in studying and monitoring the emigrant birds, determining mineral resources and their ratios underground, looking out the agricultural yields to protect them from hazards of weather and studying the formation of hurricanes.
- Explanatory and spying satellites : They are satellites which abound the information needed by military and political leaders to make decisions and monitor combats.

Science, Technology and Society:

More information about types and importance of satellites is given via the following links:



Activities and Exercises

Chapter Two

Universal Gravitation and Circular Motion

Safety Rules

Expected Learning Outcomes

By the end of this activity you will be able to:

- Determine the intensity of Earth's gravitational field.
- Find the mass of the Earth by knowing its radius.

Skills to be acquired

- Observation, Description, Draw a Conclusion

Tools and Materials

Three pendulums of different masses, A metric tape, A stopwatch, scissors

First- Practical Experiments

Measuring the mass of the Earth by knowing its radius:

Experiment overview:

You have learnt in unit two that when a body falls freely from height (d) during time (t), the acceleration due to Earth's gravitation can be calculated using the relation:

$$d = \frac{1}{2} g t^2$$

i.e

$$g = \frac{2d}{t^2}$$

(g) is called acceleration due to gravity, and is calculated from the relation:

$$g = \frac{GM}{r^2}$$

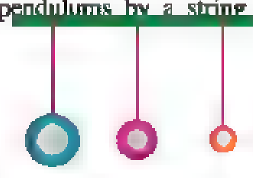
Where (G) is the universal gravitational constant, (M) is mass of the Earth, and (R) is the distance away from Earth's center. In this experiment the last term is nearly equal to the radius of the Earth (R).

Based on what preceded, the mass of the Earth can be determined by knowing its radius.

And this can be achieved through the following steps.

Procedure:

1. Hang each of the three pendulums by a string as shown in the figure. Make the distance between the center of the pendulum bob and the ground equal and large enough. Let it (d) and record its value.



2. Cut the string at the attachment point of the first pendulum. Ask your colleague to record the time taken (t) by the falling ball to reach the ground
3. Repeat the same procedure for the second and the third pendulums.

Results:

Record the results obtained in the following table:

Ball	Height d (m)	Time (t) s	Intensity of gravitational field $g=2\ d/t^2$
First ball	....	....	....
Second ball	....	....	....
Third ball	....	....	....

Through the results: Does the intensity of the gravitational field depend on the mass of the ball? Why?

....

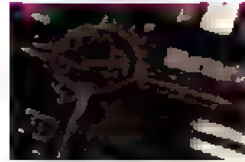
Results analysis:

By knowing the intensity of the gravitational field, that has been calculated, the Earth's radius (R = 6.38 × 106m), and the universal gravitational constant (G = 6.67 × 10-11 N.m2. kg-2). Calculate the mass of the Earth using the relation: g = GM/R2.

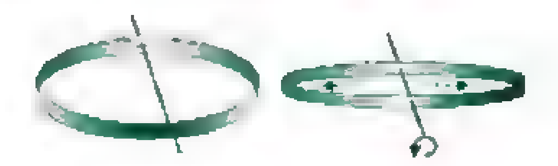
....

Second – Evaluation Activities

1. Use the site of Wikimapia to find photos taken by a satellite for your school or your home.
2. Write a research about the importance of satellites in the fields of weather forecasting, communication, agriculture, and military purposes.



3. We know that the planet Earth is not perfectly spherical but flattened at the equator. This can be attributed to the effect of the centripetal force as a result of Earth's spinning on its axis. To illustrate that, design a model as shown in figure that is built up of a metallic wire, and a ring made of a photographic plate. The ring is pierced in order to have two opposite holes and let the wire pass through them. On rotating the wire, the circular ring is flattened.



Third – Questions and Exercises

1. Choose the right answer for each of the following:
   - The acceleration due to Earth's gravity is:
     - A general universal constant.
     - Changeable according to the height from the earth's surface.
     - Different through the seasons of the year.
     - Changeable depending on the distance between the earth and the sun.
   - The velocity required by a satellite to rotate around the Earth:
     - Depends on its mass only.
     - Depends on mass of the Earth only.
     - Depends on both; the mass of the Earth and the distance between them.
     - Is constant.
   - The velocity of rotation required by the Earth to orbit the Sun depends on:
     - The mass of the Earth only.
     - The mass of the Sun only.
     - Both the mass of the Sun and the Earth, besides the distance between them.
     - The mass of the Sun and the distance between them.

2. Which point on Earth's surface has the highest linear velocity relative to the Earth's axis of rotation, a point at the Equator, or at the tropic of Capricorn or tropic of Cancer?

   ....

   ....

3. If the mass of the Planet Mercury is (3.3 × 1023 kg) and its radius is (2.439 × 106 m), what is the weight of a body of mass (65 kg) on Mercury, and what is the weight of the same body on the Earth? Knowing the Universal Gravitational Constant (G) = 6.67 × 10-11 N.m2 kg-2.

   ....

   ....

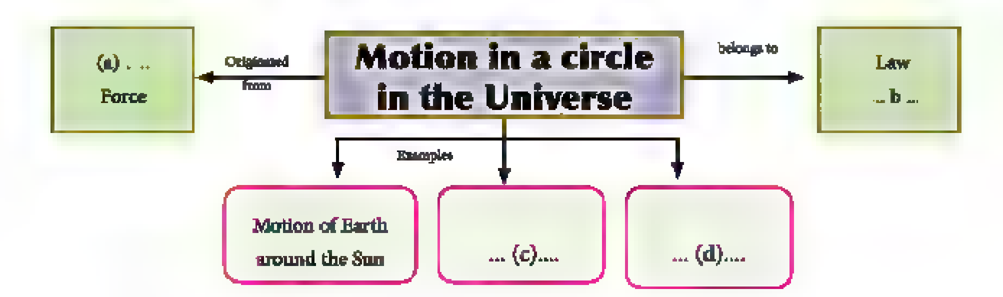
4. A satellite rotates in an orbit at a height (h) = 300 km from the Earth's surface. Find:
   - a. Its orbital velocity.
   - b. The periodic time of the satellite around the earth.
   - c. The centripetal acceleration of its motion.

Knowing that:

Radius of the Earth: $R = 6378\ km$

Acceleration due to gravity at the Earth's surface: $g = 9.8\ m/s2$

5. Complete the diagram:



6. Enjoy crosswords:

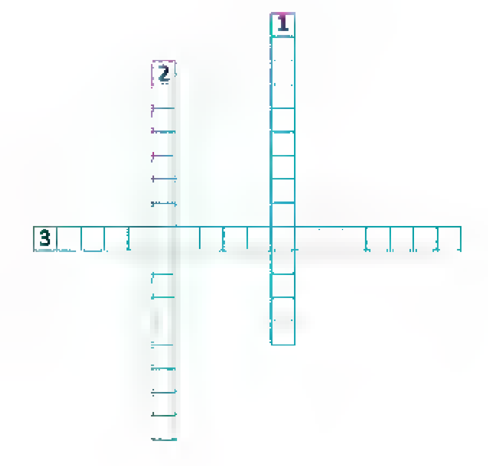
Across:

(3) The area where the forces of gravitation take place.

Down

(1) The gravitational force of the Earth on a body of mass 1kg

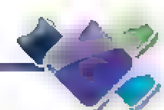
(2) The law that states: A materialistic body attracts another by a force that is directly proportional to the mass of each of them, and inversely proportional to square the distance between them.



General Exercise on the Third Unit

1 Put (√) tick to the right answer for each of the following:

1. The centripetal force on a car moving in a curve is resulted due to:
   - a. The gravitational force of Earth.
   - b. The friction force between the car tires and the road.
   - c. The inertia affecting the car driver.
   - d. The force of brakes.
2. If the radius of a circular orbit is increased to four times its original value, the centripetal force required to make the speed of the body constant would be:
   - a. Decreased to half.
   - b. Unchanged.
   - c. Increased to double.
   - d. Decreased to quarter its value.
3. Two satellites (A) and (B) rotate around the Earth, having the same periodic time. If the orbit radius of satellite (A) equals four times the orbit radius of satellite (B), the ratio between the velocity of satellite (A) to that of satellite (B) equals:
   - a. (2 : 1)
   - b. (4 : 1)
   - c. (1 : 2)
   - d. (1 : 4)
4. If the distance between the centers of two identical balls is 1 m and the force of attraction between them is 1 N, the mass of each one of them equals:
   - a. 1kg
   - b. 1.22 × 105 kg
   - c. 2 × 105kg
   - d. 0.1 kg
5. If the distance between the centers of two bodies is doubled and their masses are kept unchanged, the attractive force between them would be:
   - a. Doubled.
   - b. Halved.
   - c. Quartered.
   - d. Increased four times .



2. A helicopter toy of mass 100 g flies in a circular path of radius 1 m and rotates at a rate of 100 revolutions in 20 s

Calculate:

- a. The linear (tangential) velocity of the toy.
- b. The centripetal acceleration.
- c. The centripetal force.

3. Give reasons for each for the following:

- a. Although a body moving at a uniform circular motion acquires an acceleration, its linear speed is constant.
- b. It is dangerous to move at high velocities in curves of roads.

4. Write down the scientific term for each of the following:

- a. The motion of an object along the circumference of a circle at a linear velocity of constant magnitude and changeable direction. ( )
- b. The time taken by a body to make a complete revolution. ( )
- c. A force always acts towards the center normally to the direction of the linear velocity during the motion of a body in a circular motion. ( )

5. Choose the proper unit from column (B) that fits each quantity in column (A).

No.	(a)	(b)
1	Periodic time	$N.m^2kg^{-2}$
2	Centripetal force	m/s
3	Universal gravitational constant	m/s^2
4	Linear velocity	s
5	Centripetal acceleration	$kg.m/s^2$

6. At which height from the earth's surface a satellite should rotate so that its periodic time around the Earth equals the periodic time of Earth's spinning? Knowing that the Earth's day = 24 hours, the universal gravitational constant (G = 6.67 × 10-11 N.m2 kg-2), the mass of the Earth (ME = 5.98 × 1024 Kg), and the radius of the Earth (R = 6378 km).

In a Nutshell

Main concepts

- **Uniform circular motion:** Is the motion of a body in a circular path at a velocity, which is constant in magnitude but changeable in direction.
- **Centripetal force:** Is the force acting, continuously, in a direction normal to the motion of the body, changing its straight path into a circular path.
- **Centripetal acceleration:** Is the acceleration acquired by the body during its circular motion due to the change in its direction of velocity.
- **Periodic Time :** Is the period of time taken by a body to complete one revaluation.
- **Intensity of gravitation field at a point :** is the force of attraction acting on a body of mass *1kg* at that point. It is numerically equal to the gravitational acceleration at that point.

Relation & the main rules:

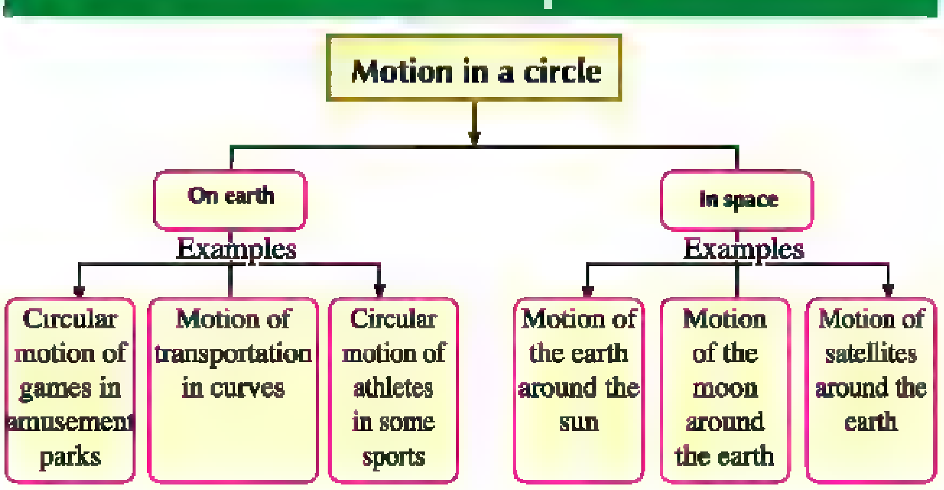
Calculating the centripetal acceleration : $a = \frac{v^2}{r}$

Calculating the centripetal force : $F = m\frac{v^2}{r}$

Calculating the force of gravitation: $F = G\frac{Mm}{r^2}$

Calculating the velocity of a satellite : $v = \sqrt{\frac{GM}{r}}$

Mind Map


Motion in a circle
On earth
In space
Examples
Examples
Circular motion of games in amusement parks
Motion of transportation in curves
Circular motion of athletes in some sports
Motion of the earth around the sun
Motion of the moon around the earth
Motion of satellites around the earth

Unit Four

Work and Energy in our Daily life

Unit Chapters

Chapter One: Work and Energy

Chapter Two: Law of Conservation of Energy

Unit Introduction

UNIT OBJECTIVES

By the end of this unit, you would be able to:

- Explain the scientific concept of work.
- Deduce that work is a scalar quantity (Not a vector quantity)
- Derive the units of energy.
- Deduce the mathematical expression for each of the kinetic energy and the potential energy.
- Draw a conclusion that the potential energy is work done.
- Compare the kinetic energy and the potential energy
- Apply the mutual interchange between the kinetic energy and the potential energy when projecting an object vertically upwards as an example for the law of conservation of energy.
- Apply the law of conservation of energy on some situations in everyday experience.

Science processes and implied thinking skills:

- Scientific interpretation
- Draws a conclusion
- Comparison
- Classification
- Generalization
- Application
- Data display skills

Included affection objectives

- Acquire positive attitudes towards rationalization of energy consumption.
- Acquire positive attitudes towards the environment
- Development tendency to study physics.

Chapter One

Work and Energy

Expected Learning Outcome

By the end of this chapter you will be able to:

- Explain the scientific concept of work.
- Deduce that work is a scalar quantity. (Not a vector quantity)
- Derive the units of energy.
- Deduce the mathematical expression for each of the kinetic energy and the potential energy.
- Draw a conclusion that the potential energy is work done.

Physical Terminology

- *Work*
- *Energy*
- *Kinetic Energy*
- *Potential Energy*

Learning Resources

- **Educational video:** work, force and displacement.
http://www.youtube.com/watch?v=n8TeJJZ8_Kk
- **Practical demonstrations:** meaning of potential energy.
http://www.youtube.com/watch?v=lLXDwJ4JUA

Work

The term work may be used in our daily experience to express a task that captured somebody's interest and is involved in the most. This task could be mental as doing homework, physical as visiting a patient, or even just being at office.

Physicists use the term work to express something really different. To do work on an object, the object must move through a displacement as a result of the acting force. If the object does not move, no work is done regardless how huge the exerted force is.

Accordingly, there are two conditions for work to be done:

1. A certain force acts on the object.
2. The object should move through a certain displacement in the direction of the force.

The following figures illustrate some examples of work:

Figure (1): The man does work on the car if moved.

Figure (2): The man does work on weightlifting

Work done (W) by a certain force (F) on an object to move it through a displacement (d) along the line of the force action can be found by the relation:

$$W = Fd$$

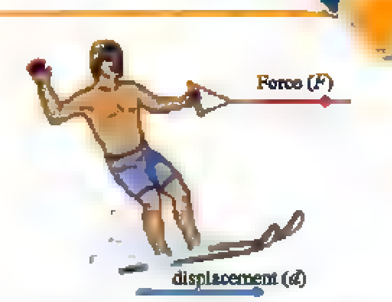


Figure (3): Work done is calculated by the dot product of displacement (d) and the force (F) acting in the same direction

Figure (4): A boy does work.

Since both force and displacement are vector quantities, their dot product results in a scalar quantity which is work. This means that work is not a vector quantity. When Lawn is mowed in a flat playground, the direction of the mower motion does not count. Mowing 50 m from east to west needs the same work done when mowing 50 m from west to east.

Work is measured in N.m. This unit is given a special name which is the Joule (J) that is named after the scientist James Joule.

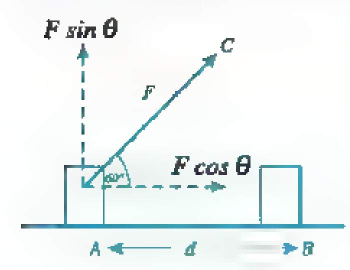
The Joule: is the work done by a force of one Newton to move an object through a displacement of one meter in the direction of the force.

Distinguished Scientists

- James Joule (1818 - 1889), An English scientist, is one of the first who realized that work generates heat. In one of his experiments he found that water temperature at the bottom of a waterfall is higher than that at the top, concluding that a part of water energy is converted into heat.

Figure (5) James Joule

If the direction of the force (F) is inclined at an angle (θ) to the direction of displacement (d) as shown in figure (6), work done can be found by the relation:



$$W = (F \cos \theta)(d)$$

$$W = F d \cos \theta$$

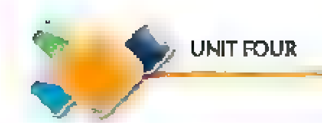


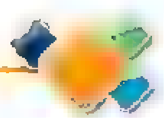
Figure (6): Work done is calculated by the relation: $W = F\,d\cos\theta$

Thinking Corner

Imagine you are pushing a wall by a force (*100 N*). Are you doing any work from physics point of view? Why?

Through the previous relation, it is clear that work can be positive , negative or zero as illustrated in the table below:

Angle θ	Work	Examples
$0 \le \theta < 90°$	Positive The person who does work.	Pulling an object
$\theta = 90°$	zero	Moving while carrying an object.
$180° \ge \theta > 90°$	Negative The object does work on the person	A person tries to pull an object while moving opposite to the direction of the force.



Solved Example

A cart of mass *(20 kg)* is pulled by a force of *(50 N)*. The line of action of the force makes an angle *(60°)* to the direction of displacement as shown in figure. Find the work done by the force to displace the cart through *(4 m)* (neglecting friction).

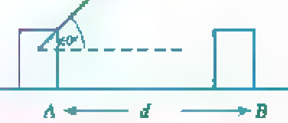
Solution.

$F = 50N$

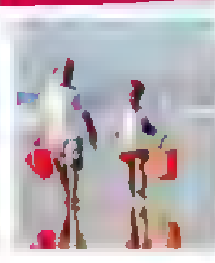
$d = 4m$

$\theta = 60°$

$W = Fd\cos\theta = (50)\ (4)\ (\cos 60) = 100\ J$



Solved Example



Calculate the work done by this girl who is carrying a bucket of mass (*300 g*) to move it through a displacement of *(10 m)* in the horizontal direction. Then, calculate the work done by the boy to lift a bucket of the same mass *(10 cm)* in the vertical direction. $(g = 10\ m/s^2)$

Solution:

Work done by the girl:

since the force exerted by the girl is perpendicular to displacement, work done equals zero.

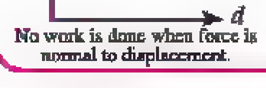
Work done by the boy:

Finding the force: $F = mg = \frac{300}{1000} \times 10 = 3N$

Work done: $W = F.\ d\cos\theta$

Since force and displacement are in the same direction, $(\theta) = 0$

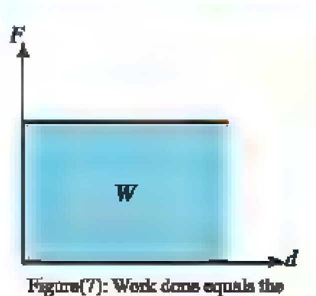
$W = 3 \times \frac{10}{100}\cos 0 = 0.3\ J$



No work is done when force is normal to displacement.

Time management

- In order not to neglect any urgent duty or activity.
- Prepare and arrange your study requirements. Organize the work environment and tools not to waste your time while looking for them.



Figure(7): Work done equals the area below the line

Graphically, we can find the work done using (force – displacement) graph as shown in the opposite diagram where the straight line expresses a constant force in magnitude and direction (F) acting on an object to displace it through displacements (d) in the direction of the force.

Referring to the definition of work:

When $\theta = 0$, work = force × displacement = length × width = the area below the curve in (force – displacement) graph.

Therefore, graphically, work done = the area below the curve in (force – displacement) graph..

2- Energy

If a certain body is able to do work, this body possesses energy. Simply, the energy of a body is its capacity to do work. Because of this, the unit of energy is the same as the unit of work which is the Joule.

In the following section we are going to discuss two forms of energy which are kinetic energy and potential energy.

(a) Kinetic Energy (KE)

When an object is acted upon by a force and the object starts to move by the impact of this force, we can say that this object has energy called kinetic energy ($K.E$).

Figure (8): Examples of kinetic energy

Suppose that you have got a car moving from rest in a straight line at uniform acceleration (a)

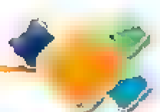
Thus, $v_f^2 - v_i^2 = 2ad$

Where v_i is the initial velocity = 0

and v_f is the final velocity.

$$v_f^2 = 2ad \qquad d = \frac{v_f^2}{2a}$$

Figure(9) A moving object possesses kinetic energy.



Multiplying both sides by (F) which is the force acting on the car during motion

$$Fd = \frac{1}{2}\frac{F}{a}v_f^2$$

Referring to Newton' second law:

$$m = \frac{F}{a}$$

Substituting in the previous equation, we find:

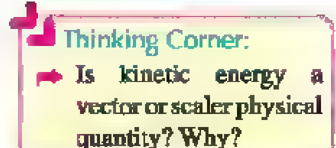
$$Fd = \frac{1}{2}mv_f^2$$

Where the left hand side (Fd) represents the work done (or the energy needed to move the car) while the right hand side $(\frac{1}{2}mv_f^2)$ represents the form of energy into which work is converted; which is known as kinetic energy (K.E)

Generally, kinetic energy of an object moving at velocity (v) is calculated by the relation :

$$K.E = \frac{1}{2}mv^2$$

- *From the previous relation, we conclude that the kinetic energy is directly proportional to the object mass and the square of the object speed.*
- *The unit of kinetic energy is the Joule, and its dimensions are ML^2T^{-2}*



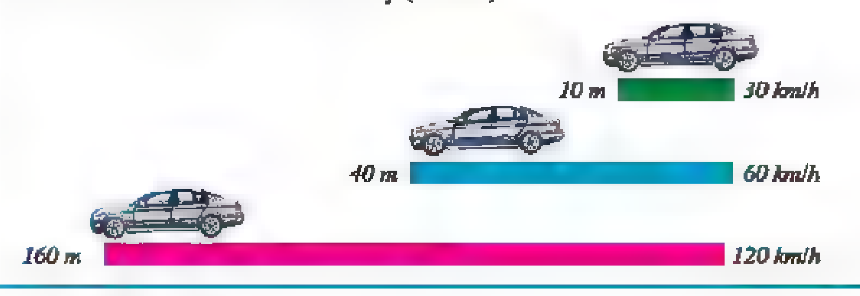
Thinking Corner:

Is kinetic energy a vector or scaler physical quantity? Why?

Life Applications

Through the relation: $K.E = \frac{1}{2}mv^2 = Fd$, the work done is directly proportional to the square of the object speed.

If we'd like to stop a car moving at velocity (60 km/h) by applying the brakes, the car would slide for a distance before stopping. This distance is four times longer than that needed if the car moves at velocity (30 km/h).



Solved Example

Calculate the kinetic energy of a car of mass *(2000kg)* moving at speed *(72 km/h)*.

Solution:

Converting the unit of velocity into m/s:

$$v = \frac{1000 \times 72}{60 \times 60} = 20\ m/s$$

$$\therefore K.E = \frac{1}{2} mv^2$$

$$= \frac{1}{2}(2000)\ (20)^2 = 400000\ J$$

(b) Potential Energy (P.E)

Energy can be stored in objects because of their new positions. This energy is called potential energy (PE). For example, compression or elongation of a spring makes its particles have new positions and hence extra potential energy known as elastic potential energy. The spring then does work to release this energy, restoring its original position. Another example, when an object is raised higher above the ground, it acquires potential energy known as gravitational potential energy. This energy is related to the object position relative to the surface of Earth. Figure (10) illustrates some examples of stored energy.

Why do electrons flow when a battery is connected to a closed circuit? | Why do corroded rocks collapse and fall? | Why does the stretched rubber band move when removing the acting force? | Why does the spring move when removing the acting force?

Figure(10): Examples of potential energy.

If an object of mass *(m)* is lifted to a height *(h)*, this object acquires potential energy *(P.E)* due to its new position. Consequently, it is able to do work when allowed to fall. Thus, the potential energy of the object in its new position has determined its ability to do work. In other words, the work done to lift the object to a certain point = potential energy of this object at this point.

$$P.E = W = Fh$$

Since the least force required to raise the object higher equals its weight *(mg)*.

So, $P.E = Fh = (mg)\ (h) = mgh$

m

Object has potential energy

h

m Earth's surface

PE = 0

Figure (11): Object *(m)* is raised to a height *(h)*

The unit of measuring the potential energy is the Joule and its dimensions are ML^2T^{-2}

Think and Answer

Calculate the work done to lift an object of mass *(50 kg)* to *(2.2m)* high above the ground.

Life Applications

- To lift a box into a truck, work must be done. In figure (12) we need a force of *(450N)* to lift the box vertically to a height of *(1m)*. On the other hand, we can raise the same box using less force (of *150 N*) using a ramp (inclined plane) but with a greater displacement (*3 m*)

Figure (12): Lifting the box vertically requires a force equal to its weight, and the work done:
$W = 450N \times 1m = 450J$

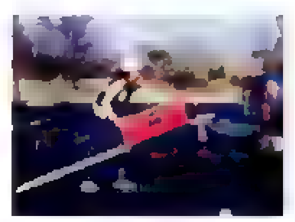


Figure (13): When using a ramp, the box requires a force less than its weight but affects it for a longer displacement
$W = 150N \times 3m = 450J$

Comparing kinetic energy and potential energy of an object:

Point of comparison	Kinetic energy	Potential energy
Definition	The energy possessed by the object due to its motion	The energy possessed by the object due to its position or state
Mathematical expression	$K.E = \frac{1}{2} m v^2$	$P.E = m g h$
Affecting factors	Increases by increasing each of: Object mass (*m*) Object velocity (*v*)	Increases by increasing each of: Object mass (*m*) Height above Earth's surface (*h*)
Unit of measurement	The Joule	The Joule
Dimensions	ML^2T^{-2}	ML^2T^{-2}

Activities and Exercises

Chapter One

Work and Energy

Safety Rules

By the end of this activity you will be able to:

- Determine the kinetic energy of a moving object.
- Deduce the relation between mass and speed of an object when its kinetic energy is constant.

Skills to be acquired:

- Recording data - Interpretation - Draw a conclusion

Tools and Materials:

Rider of mass m moving on an air track. Rubber band Photoelectric cell Electric stopwatch

First- Practical Experiments

(1) Kinetic energy of a moving object:

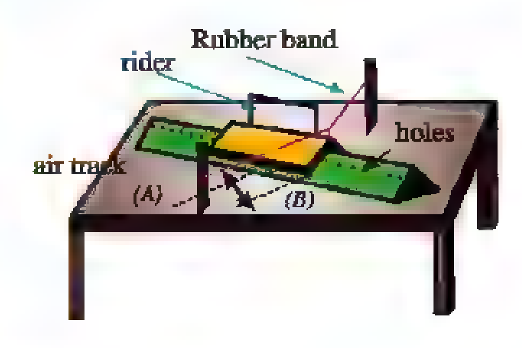
Experiment overview:

Kinetic energy is the energy possessed by an object due to its motion. It can be determined by the relation:

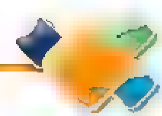
$$K.E. = \frac{1}{2} mv^2$$

From the previous relation we conclude that the square of the object speed is inversely proportional to the object mass when its kinetic energy is constant. That is what we are going to prove practically.

Procedure:



1. Displace the rider from the point (A) to point (B) as shown in figure. Then, release it to rush back.
2. Measure the time taken by the rider while moving along the air track using a photoelectric cell and electric watch



3. The rider speed (v) is determined by dividing the distance moved by the rider by time in seconds. Then, find the mass of the rider (m) in kilograms
4. The mass of the rider is changed several times and the previous procedure is repeated while its velocity is measured each time. Note that the rider should be displaced through the same distance (AB) each time. Record the results in the table below:

Results:

Rider mass *m* (kg)	Time *t* (s)	Rider speed *v* (m/s)	$\frac{1}{m}$	v^2

Using the data in the previous table, plot a graph between square of speed (v^2) on the ordinate and the reciprocal of mass ($\frac{1}{m}$) on the abscissa.

Results Analysis:

Using the obtained graph answer the following questions:

1. What is the slope of the obtained line equal to? ....
2. How can you find the kinetic energy of the rider graphically? ....
3. Is the proportionality between the square of rider speed (v^2) and its mass (m) directly or inversely? ....
4. What is the unit of measuring the kinetic energy of the rider? ....

Second – Evaluation Activities

1. Collect photos for everyday life activities that indicate doing work.
2. Download a collection of videos about Olympic and Athletics sports. Explain how work is done in each video.
3. Make a list for some examples of kinetic energy in daily life.
4. Collect a group of objects and tools that can store potential energy.
5. Write down a research via the internet about the clean energy resources that can be used in Egypt.

Third - Questions and Exercises

1 Choose the correct answer for each phrase of the following:

1 When the speed of a car is doubled, its kinetic energy ......

a. is halved .
b. is doubled.
c. increases four times.
d. remains constant.

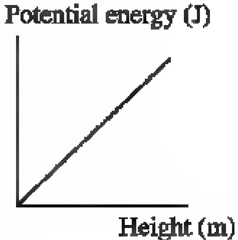
2 A man went to his apartment twice; once using the stairs and another using the elevator. Which statement is correct?

a. The man possesses more potential energy when using the stairs.
b. The man possesses more potential energy when using the elevator.
c. The man has no potential energy when using the elevator.
d. The man possesses the same potential energy in both cases.

3 Mechanical energy of an object equals ....

a. The difference between its kinetic energy and potential energy.
b. The sum of its kinetic energy and potential energy.
c. The ratio between its kinetic energy and potential energy.
d. The product of its kinetic energy and potential energy.

4 The slope of the straight line in the opposite graph represents ....

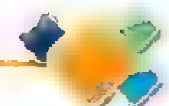


a. Object mass.
b. Object weight.
c. Object displacement.
d. Object speed.

2 An athlete of weight 700 N climbed a mountain. Find the work he did when he reached to 200 m above the ground.

3 Two boxes (A) and (B) have weights 40 N and 60 N respectively. The box (A) is on the ground while the box (B) is at 2 m high above the ground. What is the height of the box (A) so that it has the same potential energy as the box (B)?

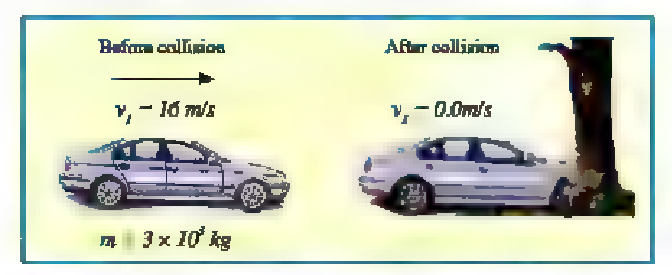
4 Find the work done to push a cart by a force 20 N through a displacement of 3.5 m.



(5) Find the kinetic energy of a car of mass 2000 kg that is moving at a speed of 60 km/h.

....

(6) A car of mass 3×10^3 kg and velocity 16 m/s crashed into a tree. The tree stayed still and the car stopped as illustrated in the figure below.



a. What is the change in the kinetic energy of the car?

....

b. What is the work done on the car front when it crashed into the tree?

....

....

c. Find the magnitude of the force acting on the car front when it is deformed by (50 cm).

....

....

(7) Enjoy crosswords:

Across:

(2) The work done by a force of one Newton to move an object through a displacement of one meter in the direction of the force

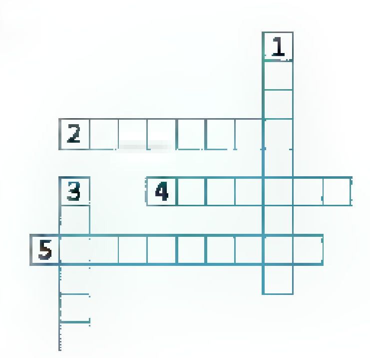
(4) The energy possessed by an object due to its motion

(5) The energy that equals the sum of the kinetic energy and the potential energy of an object

Down:

(1) The energy stored in an object due to its position

(3) The capacity to do work.



Chapter Two

Law of Conservation of Energy

Expected Learning Outcomes

By the end of this chapter you will be able to:

- Apply the mutual interchange between the kinetic energy and the potential energy when projecting an object vertically upwards as an example for the law of conservation of energy.
- Apply the law of conservation of energy on some situations in everyday experience.

Physical Terminology

- *Law of Conservation of Energy*

e- Learning Resources

- **e- game:** calculating kinetic energy and potential energy
http://www.brainpop.com/games/coastercreator/
- **Educational flash:** Mechanical energy of an object moving down an inclined plane.
https://sites.google.com/site/physicsflash/home/mechanical-energy

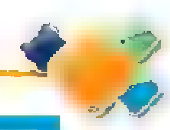
We have learnt that energy is the capacity to do work and there are several forms of energy. Coal, gasoline and other types of fuel possess stored chemical energy. On burning, this chemical energy is converted into mechanical work used to run means of transportation such as cars and trains.

Figure (14). Burning of coal used to produce mechanical work to move the train

Also, the electrical energy is converted in the electric bulb into heat and light energies, and the potential energy in a waterfall is converted into kinetic energy

There are many other examples to convert energy from one form into another. These conversions belong to the law of conservation of energy that states that:

Energy is neither created nor destroyed. Actually, it is converted from one form into another



2- Law of Conservation of Mechanical Energy

The law of conservation of mechanical energy can be verified through the concepts of the potential energy and kinetic energy as follows:

On projecting an object of mass (m) upwards against gravity from point *(1)* at initial velocity (v_i) to reach point *(2)* at final velocity (v_f), the potential energy of the object increases with height while its kinetic energy decreases due to a decrease in its velocity.

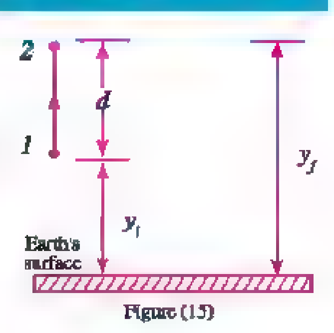


Figure (15)

$$a = -g$$

$$v_f^2 - v_i^2 = 2(-g)d$$

$$v_f^2 - v_i^2 = -2gd$$

multiply by $(\frac{1}{2} m)$

$$\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = -mgd$$

$$\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = -mg(y_f - y_i)$$

$$\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = -mg\,y_f + mg\,y_i$$

$$mg\,y_f + \frac{1}{2}mv_f^2 = mg\,y_i + \frac{1}{2}mv_i^2$$

Thus:

$$PE_f + KE_f = PE_i + KE_i$$

Figure (16): Potential energy increases with hight while kinetic energy decreases.

This means that:

The sum of potential energy and kinetic energy at point (1) = the sum of potential energy and kinetic energy at point (2)

Law of conservation of mechanical energy: The sum of potential energy and kinetic energy of an object at any point on its path under the effect of gravity only is constant and known as the mechanical energy.

Mechanical energy = potential energy + kinetic energy = constant

From the last relation we conclude that the increase in kinetic energy of an object will be at the expense of its potential energy, i.e. potential energy decreases, and vice versa. (Law of conservation of energy)

Solved Example

A static object at *(30 m)* high above the ground has potential energy *(1470 J)*. If this object falls neglecting the air resistance and consider $g = 9.8\ m/s^2$, find:

1. the kinetic energy and potential energy of the object at *(20 m)* high.
2. the object velocity just before hitting the ground.

A $y_i = 30\ m$, $v_i = 0$

B $y_f = 20m$, $v_f = ?$

C $y_{f2} = 0$, $v_{f2} = ?$

Earth's surface

Solution:

At point A

$$P.E = mgh = 1470\ J$$
$$m \times 9.8 \times 30 = 1470\ J$$
$$m = 5kg$$

1. applying the law of conservation of mechanical energy at the points *B* and *A*.

$$mg\,y_f + \frac{1}{2}mv_f^2 = mg\,y_i + \frac{1}{2}mv_i^2$$
$$5 \times 9.8 \times 20 + \frac{1}{2} \times mv_f^2 = 5 \times 9.8 \times 30 + 0$$
$$\frac{1}{2}mv_f^2 = 490\ J$$

$\therefore$ kinetic energy of object at 20 m high is *(490 J)*

Potential energy of object at *(20 m)* high:

$P.E_f = 1470 - 490 = 980J$

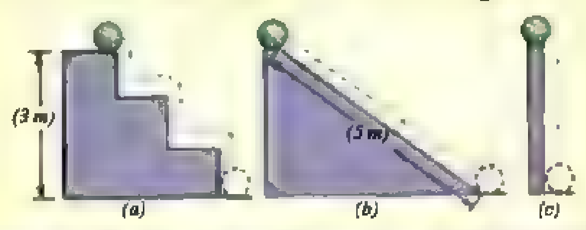
2. To find the object velocity just before hitting the ground:

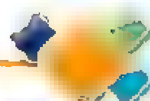
applying the law of conservation of mechanical energy to the points *C*, *A*

$$5 \times 9.8 \times 30 + 0 = 0 + \frac{1}{2} \times 5 \times v_{f2}^2 \qquad \therefore v_{f2} = 24.25\ m/s$$

Thinking Corner

- Imagine three possible paths for a ball lifted from the ground to reach the same heigh each time. Which path makes the work done to move the ball the greatest?
  - Path *a*
  - Path *b*
  - Path *c*
  - the same in all paths





Law of conservation of energy in everyday experience:

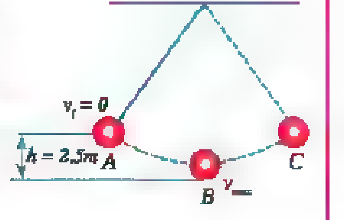
Figure (17): Mutual transformation of KE and PE of an object

Projecting an object in air upwards is an example for the conservation of energy, or the mutual transformation of kinetic energy and potential energy. For example when a ball is thrown from the ground upwards, potential energy of the ball is zero at the ground while kinetic energy maximum. As the ball rises in the air, its potential energy increases at the expense of its kinetic energy. Potential energy reaches its greatest value at the highest possible point reached by the ball where its kinetic energy becomes zero. Next to that the ball falls to ground and the kinetic energy increases gradually while potential energy decreases till it becomes zero at the ground.

There are many examples of such transformation as indicated by the following link:

Solved Example

The diagram illustrates a ball hung by a thread swinging in a certain vertical plane. If the ball mass is *(4kg)* and ($g = 9.8 m/s^2$), find the greatest velocity of the ball during oscillation, neglecting the air resistance.



Solution:

greatest velocity of the ball during oscillation is reached at the point *(B)*

. applying the law of conservation of mechanical energy at the points *B* and *A*

$$mgh + 0 = \frac{1}{2} mv_f^2 + 0 \qquad 4 \times 9.8 \times 2.5 = \frac{1}{2} \times 4 \times v_f^2$$

$v_f = 7\ m/s$

Activities and Exercises

Chapter Two

Law of Conservation of Energy

Safety Rules

Expected Learning Outcomes

By the end of this activity you will be able to:

- Verify the Law of Conservation of Mechanical Energy

Skills to be acquired

- Recording data Interpretation Draw a conclusion

Tools and Materials

A tennis ball Digital scale Sticker tape Stopwatch Meter tape

First- Practical Experiments

(1) Law of conservation of energy:

Experiment overview:

Previously we have studied that the sum of potential energy and kinetic energy at any point on its path under the effect of gravity only is constant and known as the mechanical energy. This means that the increase in kinetic energy of an object will be at the expense of its potential energy, i.e. potential energy decreases, and vice versa.

Procedure:

1. Measure the mass of the tennis ball in grams using a digital balance and then convert it into kilograms.

   $m = \ldots\ldots\ g = \ldots\ldots\ kg$

2. Stick pieces of a sticker tape on the wall at different heights (1m, 2m, 2.5 m ...etc.)
3. Hold the tennis ball at 1 m high and allow it to fall to the ground. Measure the time taken by the ball to reach the ground.
4. Repeat the previous step several times and find the average time.
5. Repeat the previous steps (3) and (4) for the different premeasured heights (2m, 2.5 m ...etc.)
6. Record the obtained results in the following table:

Results :

	Time t (s)		
Height h (m)	First trial	Second trial	Third trial
1			
2			
2.5			
Average value			

1. Find the potential energy (P.E) of the ball at the different heights using the relation:

$$P.E = mgh$$

Given that: $g = 9.8\ m/s^2$

2. Assuming that the ball has fallen from rest, its initial velocity (v_i) equals zero. The final velocity (v_f) of the ball just before hitting the ground can be found by the relation:

$$v_f = gt$$

3. By knowing (v_f), the kinetic energy (KE) of the tennis ball just before hitting the ground can be found by the relation:

$$K.E = \frac{1}{2} mv^2$$

Record the results in the following table:

Height above ground	1	2	2.5
potential energy (PE) at that height			
kinetic energy (KE) just before hitting the ground			

Results Analysis:

1. Comparing the results for each of KE and PE in each case, what do you notice?

2. What are the reasons that may cause the values of KE and PE in each case not to be identical?

3. Do the obtained results practically agree with your expectations?

Second – Evaluation Activities

1. Collect photos from different resources such as references, magazines, and the internet that illustrate the transformation of energy from one form into another.
2. Design a device that can convert energy from one form into another using raw materials from your environment.
3. Prepare a wall display provided with photos for some games in the amusement park in which kinetic energy is transformed into potential energy and vice versa.
4. Make a list for some educational and scientific sites that discuss the concept of the mechanical energy.

Third – Questions and Exercises

1. An object is projected vertically upwards at velocity 20 m/s. Neglecting the air resistance, find each of the following:
   - a. The maximum height reached by the object.
   - b. The velocity of the object at 10 m high above the ground.

2. Using the opposite diagram, find each of:
   - a. The potential energy of the bicycle rider at the point (a)
   - b. The potential energy of the bicycle rider at the point (b)
   - c. The total energy of the bicycle rider at the point (b)

3. Enjoy crosswords:

Across:

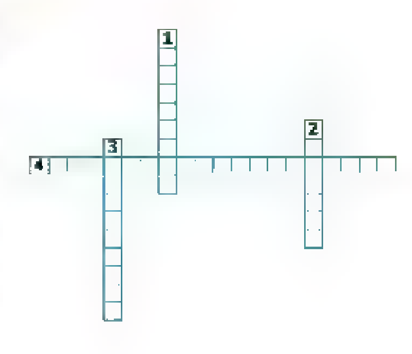
(4) Name of the law that states: Energy is neither created nor destroyed but it is converted from one form into another

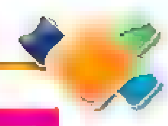
Down:

(1) The energy stored in an object due to its position

(2) The energy possessed by an object due to its motion

(3) The energy that equals the sum of object kinetic energy and the potential energy





General Exercise on the Fourth Unit

1 Choose the correct answer for each phrase of the following:

a The kinetic energy of an object is 4 J. what is its kinetic energy if its speed is doubled?

- *8J*
- *16J*
- *4J*
- *0.8J*

b An object of mass 2 kg is at 5 m high above the ground. Its potential energy equals:

- *98J*
- *10J*
- *2.5J*
- *9.8J*

c The stored energy in a compressed spring is:

- kinetic energy.
- potential energy.
- nuclear energy.
- repulsion energy.

d If an object is projected upwards, which quantity becomes zero at its maximum height?

- Gravitational force.
- object acceleration.
- potential energy.
- object velocity.

2 Give reasons for:

a Work is a scalar quantity.

b Potential energy of water is greater at the top of a waterfall than that at the bottom.

c A person carrying a suitcase does not do any work when moving horizontally.

3 A force of 100 N acts on an object to displace it through 2.5 m. find the work done by this force in the following cases:

a If the force acts in the same direction of object motion.

b If the force direction makes an angle 60° to the direction of object motion.

c If the force acts perpendicular to the direction of object motion.

4 Calculate the mass of an object if its potential energy at a point 5 m high above the ground equals 980 J, and acceleration due to gravity = 9.8 m/s^2.

5 A ball of mass 0.5 kg is projected vertically upwards. If its velocity at 4 m high is 3 m/s, find the work done to project the ball given that acceleration due to gravity = 10 m/s^2

6. An object of mass 4 kg falls freely from 20 m high above the ground. Fill in the blank cells in the following table, neglecting the air resistance and given that ($g = 10\ m/s^2$)

Point	Displacement (m) starting from point of falling	Potential energy (J)	Object velocity	Kinetic energy (J)	Mechanical energy (J)
A	0	....	....	....	....
B	....	....	5m/s	....	....
C	....	400 J	....	....	....
D	....	....	....	800 J	....

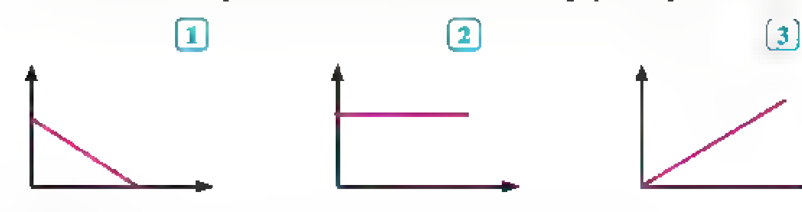
From the results you obtained, define the point, during falling, at which:

a. The mechanical energy of the object equals its kinetic energy

b. The mechanical energy of the object equals its potential energy

c. The kinetic energy of the object equals its potential energy

6. A body has been projected vertically upwards. You have got three graphs (1, 2 and 3); each of them expresses the relation between two physical quantities.



Decide on the graph represents that the relation between:

a. potential energy and object height above the ground.

b. kinetic energy and object height above the ground.

c. mechanical energy and object height above the ground.

In a nutshell

First: Main Concepts

- **Work :** the dot product of the force and displacement of an object in the direction of the force. It is a scalar quantity and measured in Joule.
- **The Joule:** the work done by a force of one Newton to move an object through a displacement of one meter in the direction of the force.
- **Energy:** the capacity to do work.
- **Kinetic energy:** the energy possessed by an object due to its motion.
- **Potential energy:** the energy stored in an object due to its position.

Second: Main Laws

- **Law of conservation of energy:** Energy is neither created nor destroyed but it is converted from one form into another.
- **Law of conservation of mechanical energy:** The sum of potential energy and kinetic energy of an object at any point on its path under the effect of gravity only is constant.

Third: Main Relationships

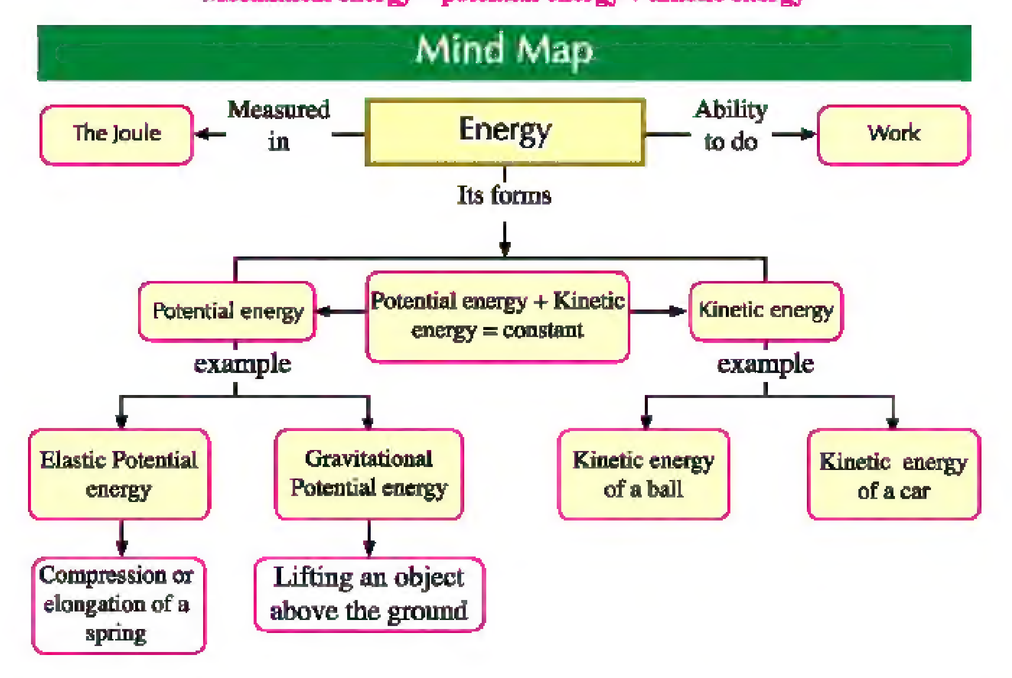
$$W = Fd\cos\theta$$

$$K.E = \frac{1}{2}mv^2$$

$$P.E = mg\,h$$

Mechanical energy = potential energy + kinetic energy

Mind Map



المواصفات الفنية:

مقاس الكتاب:	$\frac{1}{8}$ (٥٧ × ٨٢) سم
طبع المتن:	٤ لون
طبع الغلاف:	٤ لون
ورق المتن:	٨٠ جم أبيض
ورق الغلاف:	٢٠٠ جم كوشية
عدد الصفحات بالغلاف:	١٥٢ صفحة
رقم الكتاب:	